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HELICOPTER DYNAMIC PERFORMANCE PROGRAM
VOLUME II - USER'S MANUAL

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Final Report

Approved for public release;
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Prepared for

APPLIED TECHNOLOGY LABORATORY
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Fort Eustis, Va. 23604

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APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

This report documents the engineering development and implementation procedures of an energy and force balance method of analysis for calculating the space-time-power relationship of a rotorcraft in steady or transient flight. While the current software and associated reports form a good basis from which a comprehensive energy-type rotorcraft analysis tool can be refined, both are in a state of flux. Through continued exercise by qualified users, the code and documents will be progressively refined to a state that they will accomplish the intended purpose. It is therefore fully anticipated that these documents (user's and engineer's manuals) will be subsequently revised and republished or errata sheets issued at an appropriate juncture.

The computer program resulting from this contract will be provided to qualified users, upon request, for use in the design and analysis of rotary-wing aircraft.

The project engineer for this contract was Mr. G. T. White, Aeromechanics Technical Area, Aeronautical Technology Division. Technical review of this report was also provided by Messrs. W. A. Pleasants of Design Integration and Analysis Technical Area, and E. E. Austin of Aeromechanics Technical Area.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report provides the instructions for operating the Helicopter Dynamic Performance Computer Program.

The program provides a means of rapidly estimating rotorcraft takeoff and landing capabilities from or to any given heliport size or location.

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Block 20 (cont'd)

Proper application of the instructions outlined herein for computing operational capabilities and flight procedures can minimize the risk and cost of testing rotorcraft capabilities in the takeoff, landing and emergency of flight.

The program has been written in FORTRAN IV and designed primarily for interactive operation on the IBM 360/65 computer system, in conjunction with a PDP-11 and DEC- GT-40 scope and a Houston bed type plotter. Interfacing with a Tektronix storage tube Model 4010, 4012 or 4014, the Houston plot bed and the IBM 360/65 is also available. Options for batch processing with and without Houston plots has been provided.

With minor modifications the program can also be interfaced with a CDC or UNIVAC 1110 in lieu of the IBM 360/65. Program modifications required for CDC 6600 compatability are covered in Section 9 of this report.

TABLE OF CONTENTS

TABLE OF CONTENTS - Continued

LIST OF ILLUSTRATIONS

1.0 INTRODUCTION

A computer program for calculating the space-time relationship of a rotorcraft in steady or dynamic (accelerating) flight has been developed.

The method of analysis is basically an energy and force balance procedure. It assumes a quasi-static flight condition during finite time intervals. The translational displacements across each time interval are summed to generate the resulting flight path.

The program has the capability of analyzing normal takeoff and landings (full powered flight) along with evaluating the effects of sudden engine malfunction during these maneuvers.

Provisions for use of auxiliary power devices, releasing or picking up external loads, use of drive train fly wheels,and deployment of drag brakes are included to examine their effects on operating capabilities during emergency situations.

This document covers the input requirements and generalized procedures for successful operation of the computer program. The engineering details of the analysis procedures used is covered in Volume I.

It is recommended that the program users familiarize themselves with the program input requirements prior to any attempt in running the program.

Although not a necessity, a basic background in helicopter flying procedures will be helpful in the successful operation of the program.

2.0 PROGRAM INPUT REQUIREMENTS

The Helicopter Dynamic Performance Program input requirements have been broken down into four basic categories:

1. Basic Airframe Definition
2. Initial Flight Conditions
3. Flight Events
4. Program Options

The basic definitions, input locations and units of the required variables are contained in the following list. A detailed explanation of each of these variables is given in Section 2.1. It is recommended that Section 2.1 be used as a program loading guide until complete familiarization of the full definition and input form requirements has been gained.

Location	Definition	Units
	(BASIC AIRFRAME)	
1	Number of main rotor blades - per rotor for tandems, b.	--
2	Main rotor blade root cutout	PCT R
3	Main rotor blade chord @.75 radius, C	Ft
4	Main rotor radius, R	Ft
5	Main rotor inertia about rotational axis, J_M	Ft-lb-Sec^2
6	Equivalent linear blade twist θ_e	Deg
7	Rotational velocity of main rotor @100% N_R	Rad/Sec
8	Rotorcraft Type: 0. Single main rotor with tail rotor	--
	1. Tandem rotor	--
	2. Single main rotor with tilted tail rotor	--
9	Horizontal distance between rotor centroids	Ft
	Main to Tail Rotor - Single, Fwd to Aft Rotor Tandem	

Location	Definition	Units
10	Vertical distance between rotor centroids	Ft
11	Yaw angle for tandems - tail rotor tilt angle for single rotor types	Deg
12	Rolling coefficient of friction	--
13	Airframe parasite drag area, F	Ft^2
14	Airframe vertical drag, D_V	PCT GW
15	Vertical height from main wheels (skids) to main rotor centroid	Ft
16	Center-of-gravity location horizontal from main Rotor C_L. Positive forward. Vertical from rotor centroid. Input as: 10.0* Horizontal Distance. Vertical Height/100	In
17	Longitudinal airframe inertia. I_{XX}	$Ft\text{-}Lb\text{-}Sec^2$
18	Lateral airframe inertia. I_{YY}	$Ft\text{-}Lb\text{-}Sec^2$
19	Vertical airframe inertia. I_{ZZ}	$Ft\text{-}Lb\text{-}Sec^2$
20	Main rotor shaft tilt - longitudinal, positive forward	Deg
21	Main rotor shaft tilt - lateral, positive toward right	Deg
22	Blade flapping moment (first)	Slug-Ft
23	Blade hinge offset	Ft
	(INITIAL FLIGHT CONDITIONS)	
24	Desired height at edge of heliport or cyclic flare height for autorotations	Ft
25	Pressure altitude at takeoff/landing site (i.e., heliport location)	Ft
26	Ambient air temperature at takeoff/landing site (i.e., heliport location)	Deg C
27	Aircraft operating weight	Lb

Location	Definition	Units
28	Initial wheel (or skid) height	Ft
29	Initial horizontal velocity (ground speed)	Kt
30	Initial vertical velocity	Ft/Min
31	Initial distance	Ft
32	Horizontal distance from main wheels to edge of heliport	Ft
33	Vertical height from ground plane to heliport (assumes elevated heliport)	Ft
34	Use 1 for free-flight operation -1 if rotorcraft is restrained bef re takeoff	--
35	Maximum allowable C_T/σ permitted during flight	--
36	Internal use only.	
37	Initial power required (if not known input excessively high value)	Shp
38	Initial rotor RPM	PCT
39	Initial longitudinal tip path plane attitude	DEG
40	Initial lateral tip path plane attitude	DEG
41	Initial rotorcraft heading	Deg
42	Wind	Kt
43	Wind direction (measured from nose of rotorcraft)	Deg
44	Wind inclination from horizontal (positive down)	Deg
45	Collective time delay (auto entry)	Sec
46	Longitudinal cyclic delay	Sec
47	Lateral cyclic delay	Sec
48	Autorotation entry recovery rpm	Pct

Location	Definition	Units
	(FLIGHT CONDITION PHASES)	
49	Number of events desired (10 maximum)	--
50.	Type of flight: -2.J @EMP/10 Landing	--
	-1.J @EMP/10 Rejected Takeoff	--
	1.J @EMP/10 Takeoff	--
	2.J @EMP/10 Balked Landing	--
51-60	Events Options: -2. Horizontal Speed	Kt
	-1. Horizontal Distance	Ft
	0. Time	Sec
	1. Vertical Height	Ft
	2. Angle of Turn (from present heading)	Deg
61-70	Desired condition at end of event (J). Units based on U(51-60)	--
71-80	Desired speed at end of event (J)	Kt
81-90	Desired power at end of event (J)	Shp
91-100	Time of power application during event (J)	Sec
101-110	Desired rpm at end of event (J)	Pct
111-120	Time of rpm change during event (J)	Sec
121-130	Maximum longitudinal tip path plane attitude during event (J)	Deg
131-140	Time to longitudinal tip path plane attitude during event (J)	Sec
141-150	Phase-Out speed for longitudinal TPP attitude during event (J)	Pct (71-80)
151-160	Maximum lateral tip path plane attitude during event (J)	Deg
161-170	Time to lateral tip path plane attitude during event (J)	Sec

Location	Definition	Units
171-180	Turn angle desired during event (J) (from present heading)	Deg
181-190	Phase out turn angle	Pct (171-180)
191-200	System mechanical efficiency M/R power/total power	Pct Total Shp
201	Fixed power losses	Shp
	(OPTIONS)	
202	Height velocity avoidance 0. No.,1.Yes	--
203	Critical speed on H-V envelope	Kt
204	Critical height on H-V envelope	Ft
205	Horizontal takeoff procedure 0. No, 1. Yes	--
206	Delta horsepower for horizontal takeoff procedure	Shp
207	Auxiliary power units: 0. off, 1. J/100 ON. or rotor tip rockets: 0. off, 2.J/100 ON.	Shp Lb
208	Horsepower available from auxiliary power units or thrust available from tip rockets - per unit	Lb
209	Delay time prior to ignition (from start of event J)	Sec
210	Time auxiliary power is available	Sec
211	Mass moment of inertia of flywheel	$Ft\text{-}Lb\text{-}Sec^2$
212	RPM ratio of flywheel to main rotor RPM $\frac{RPM\ FW}{RPM\ MR}$	--

Location	Definition	Units
213	External propulsion units or in-flight configuration changes	--
	0. No., 1. J/100 external propulsion units	--
	-1. J/100 in-flight configuration change	--
214	Delay time prior to ignition or change in configuration (from start of event J)	Sec
215	Burn time of external propulsion units	Sec
216	Thrust per unit or configuration weight change	Lb
217	Mount angle of auxiliary propulsion units (Vertical = 0^o)	Deg
218	Number of external propulsion units or change in airframe F due to configuration change	-- or Ft^2
219	Supplement output file unit, must be set to file unit +.1 for last case of batch processing with plots. Defaults to unit 10 if not input.	--
220	Basic print file output unit. Plot option. Print unit defaults to unit 6 if not input. Plot option .1 - Tektronix & CAL-COMP (interactive) .2 - CAL-COMP only (interactive) .3 - CAL-COMP batch	--
221-224	User δ-C_{L_M} coefficients (cubic)	--
225	Reserved for internal use	--
226	Distance from main rotor C_L to wing ¼ chord. Horizontal, positive aft.	In
227	Distance from main rotor centroid to wing chord @ ¼ chord pt. vertical, positive below rotor	In

Location	Definition	Units
228	Wing span - Tip to tip.	Ft
229	Wing chord at .75 semi-span	Ft
230	Wing taper ratio Tip chord/Root chord	--
231	Optimizer switch	
	1.0 Optimize H-V Envelope 1.1 Optimize low Hover hgt. only 2.2 Optimize H-V Nose Point only 2.3 Optimize high Hover hgt. only 1.4 Optimize max range in auto-rotation -1.0 Estimate H-V envelope only 2. VV EMP/100 Calculate power required at EMP for specified VV @ EMP	VV in Ft/Min
232	Desired vertical impact speed at touch-down. Ground speed.	Ft/Sec
233	Remaining engine power available after single engine malfunction.	Shp
234	Min. Max/100. Horizontal touchdown speed desired. Ground speed.	Kt
235	Min. Max/100. Body attitude at touch-down desired	Deg
236	Max.Min/100. Rotor speed desired at touchdown	Pct
237	Height for program take-over control during landing maneuvers	Ft
238	Min. Max/100. Theta-75 limits (Collec-tive Control)	Deg
239	K Factor for Theta-75 Calculations, 2.66 by default	--
240	Known Theta-75 for initial point	Deg
241-250	Delta Theta-75 During event J	Deg
251-260	Time step for Delta Theta-75	Sec
261	See optimization loading instructions	--

Location	Definition	Units
262-297	Reserved for further development.	--
298	Airframe pitch damper Use 0.1 for Teetering rotors 0.5 for Articulated - Rotors	--
299	Airframe roll damper Use 0.1 for Teetering rotors 0.5 for Articulated rotors	--
300	User imposed time limit on flight	Sec

2.1 DETAILED DESCRIPTION OF INPUT REQUIREMENTS

The basic input list provided in Section 2.0 gives a brief definition for each input. A more detailed definition is provided here to avoid confusion.

Input Location	Definition
	AIRFRAME
1:	Number of main rotor blades. This refers to the number of blades on any one rotor head. Thus for tandem rotor machines which have eight total blades but two rotor heads, the input would be 4. Co-axial rotors not available.
2:	Main rotor blade root cutout. This input refers to that portion of the blade radius which does not carry the full blade chord. It is input as a percent of blade radius and measured from the center of rotation.
3:	Main rotor blade chord @ .75 radius. This refers to the thrust weighted equivalent blade chord. It's use provides for analysis of tapered blades as well as rectangular planforms. It is input in units of feet.
4:	Main rotor radius. The blade radius is measured from the center of rotation to the blade tip. It is input in the units of feet.
5:	Main rotor inertia about rotational axis. The rotor inertia can be calculated from the equation

$$I_R = b \int_e^1 r^2 dm$$

where
- b is number of blades/rotor
- dm is elemental blade mass
- r is radial distance to center of m
- I_R is rotor inertia

Usually the mass distribution of the rotor head sections are not known. To compensate for this the integral is generally carried out from $\int_e^1$ where e is the radius to some known weight point on the blade. The total rotor inertia is then increased by 10% to account for the rotor hub effects. The units are ft-lb-sec^2.

Input Location	Definition
6:	Equivalent linear blade twist. This input relates the blade twist distribution to a linear twisted blade. A negative (-) value indicates washout. If the blade has a compound type twist the input value θ_e can be computed from the equation

$$\int_0^1 \left|\hat{\theta}_e(x-.8)\right| x^3 dx = \int_0^1 \left|\hat{\theta}_x\right| x^3 dx$$

where $x = r/R$

^ denotes referenced to 0 twist @ X = .8

7:	Rotational velocity of main rotor. This input is in radians/sec and refers to the rotor rpm which is defined as the 100% rpm design point.
8:	Rotorcraft type. This input controls the program branching for analysis of various helicopter types. The inputs for the various types are: 0. Single main rotor 1. Tandem rotor 2. Single main rotor with tilted tail rotor
9:	Horizontal distance between rotor centroids. This input is the horizontal distance, in feet between the main and tail rotor for single-rotor helicopters for tandem rotors it is the dimension between the fore and aft rotors.
10:	Vertical distance between rotor centroids. This refers to the displacement vertically between the main and tail rotor, or fore and aft rotors for tandem. The dimension is in feet. A minus (-) value would indicate that the tail rotor or aft rotor is below the main or forward rotor, respectively.

Input Location	Definition
11:	Yaw angle for tandems - tail rotor tilt angle. Tandem rotor helicopters are more efficient in acceleration (in a yawed attitude). In some circumstances it could be appropriate to evaluate variations in yaw angles during takeoff maneuvers. The airframe parasite drag (Location 13) should be adjusted according to the yaw angle used. For single main rotors with tilted tail rotors this input refers to the angle of tilt. 0 deg. is assumed to be vertical. A positive tilt angle will yield an upward component of thrust. The input is in degrees.
12:	Rolling coefficient of friction. This input refers to the friction coefficient between the wheels and runway surface type for free rolling wheels. The braking friction coefficient is assumed to be eight times this input value and is used for rejected takeoffs and landing maneuvers after touchdown. For skid type gears (Friction coefficients 0.29 to 0.31), the program will not adjust this input a[illegible]er touchdown.
13:	Airframe parasite drag area. This [illegible] represents the airframe drag force related to the area [illegible] flat plat which would yield the same force at any given speed. The determination of this area is exclusive of the rotor system profile drag forces. The units are square feet.
14:	Airframe vertical drag. This input represents the drag force acting in the vertical direction. Its evaluation is determined from an out-of-ground effect hover analysis. The input value is expressed as a percentage of the helicopter operating weight.
15:	Vertical height from main wheels (skids) to main rotor centroid. Input units are in feet.

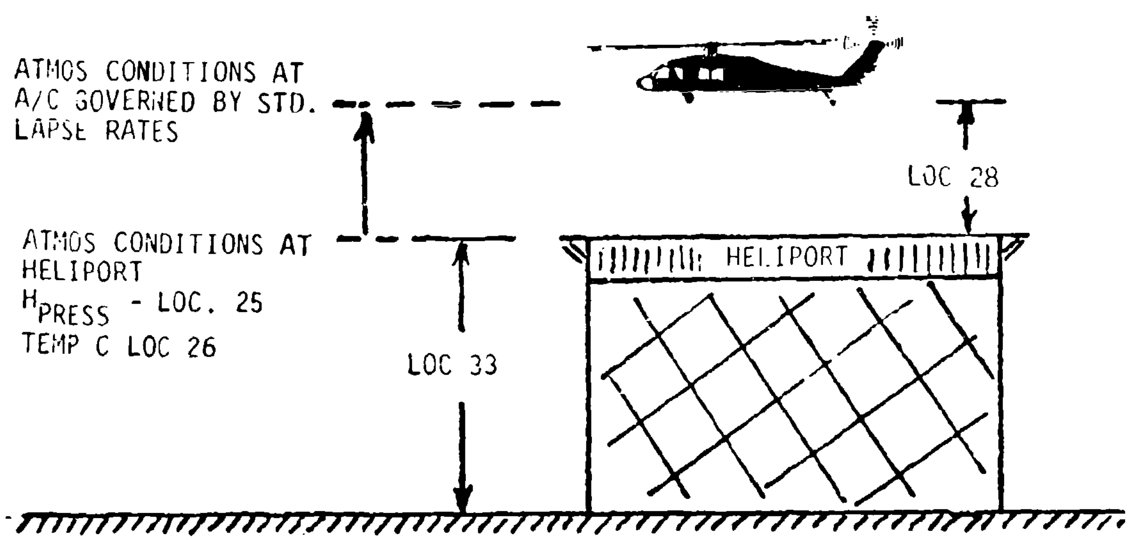
Input Location	Definition
16:	Airframe center of gravity location. This input locates the airframe center of gravity with respect to the main rotor. For tandem rotors the forward rotor is used as the reference point. The input value consists of two parts. The number in front of the decimal point refers to ten times the horizontal displacement from the main (forward) rotor centroid to the cg. A positive value is assumed to be forward of the main rotor. The number after the decimal point refers to the vertical distance between the cg and the main (forward) rotor centroid divided by 100. The units are in <u>inches</u>. Example: Single rotor cg location 5 inches forward of and 67 inches below main rotor. Input 50.67 Tandem rotor cg location 235 inches aft of and 65 inches below forward rotor. Input -2350.65
17:	Longitudinal airframe inertia, I_{xx}. This refers to the airframe's resistance to rolling moments. Input units are in.-ft-lb-sec^2.
18:	Lateral airframe inertia, I_{yy}. This refers to the airframe's resistance to pitching moments. Input units are ft-lb-sec^2.
19:	Vertical airframe inertia, I_{zz}. This refers to the airframe's resistance to yawing moments. Input units are ft-lb-sec^2.
20:	Main rotor shaft tilt (longitudinal). For cruise trim considerations the main rotor shaft generally is tilted forward. This input refers to the tilt angle measured from a line perpendicular to the airframe longitudinal axis. It is input in degrees and is positive forward.
21:	Main rotor shaft tilt (lateral). For lateral trim considerations the main rotor shaft could be tilted. This input refers to the tilt angle measured from a vertical line perpendicular to the airframe lateral axis. It is input in degrees and is positive to the right when viewing from the rear.
22:	Blade flapping moment (first). The first moment of blade flapping about the flapping hinge is input in this location. If the blade hinge offset is 0 (teetering rotors),no input is required. The units are slug-ft.

Input Location	Definition
23:	Blade hinge offset. This input refers to the distance from main rotor center of rotation to the blade flapping hinge. The three general rotor types are handled as follows: teetering - no hinge, rigid - virtual hinge location, articulated - physical hinge location. It is input in feet.

INITIAL CONDITIONS

24:	Desired height at edge of heliport or cyclic flare height for autorotations. For landings this input refers to the clearance height desired at the heliport edge. All distances are referenced to the heliport edge in this mode. All heights are referenced to the wheels (skids). For autorotations this input refers to the cyclic flare point and all distances are referenced to it. This location can be used for takeoff modes to trap out the distance required to the specified height. Negative values can be input in takeoff mode. A value of 50 feet is assumed if the absolute input value is less than 1. Units are in feet.
25:	Pressure altitude at takeoff/landing site (ie, the heliport). The ambient pressure altitude measured at the heliport is the input required here. The density altitude is computed using the standard pressure altitude lapse rate. Units are in feet.
26:	Ambient air temperature at takeoff/landing site (ie, the heliport). The ambient temperature measured at the heliport is input here. The density altitude is computed using the standard temperature lapse rate. Units are in degrees centrigrade (celcius).
27:.	Aircraft operating weight. This input refers to the all-up weight of the helicopter to be used in the analysis. Weight changed due to fuel burn off is not considered. Units are in pounds.

Input Location	Definition
28:	Initial wheel height. This input refers to the vertical displacement from the heliport to the main wheels (skids) at the initial point of the flight. It is positive if the helicopter is above the heliport. Negative values can be used with discretion if it is applied to input locations 31-33 and 50. The atmospheric conditions at the helicopter are computed from the input heliport location conditions using the standard lapse rates.



29:	Initial horizontal velocity (ground speed). The initial horizontal velocity is input in this location. This input alsways refers to ground speed. It is input in knots.

Input Location	Definition
30:	Initial Vertical Velocity. This input is the vertical velocity at the start of the flight. If the landing mode is used, Location 50 set to -2, a negative input will hold a constant rate of descent, at the input value, provided sufficient power is available. If the input is positive, a constant angle of descent is assumed. The input value is used as this angle of descent. This angle will be maintained provided sufficient power is available. This input is ignored if the power available is 0. (autorotation). Units are in ft/min if negative, and degrees if positive.
31:	Initial distance. This input is generally a 0. Output distances for takeoffs and rejected takeoffs are referenced to this point. See Location 24 for landing distance reference points. Special problems could require a distance input such as acoustical analysis evaluations.
32:	Distance from main wheels to edge of heliport. This input locates the helicopter horizontally on the heliport. It is only appropriate for takeoff and rejected takeoff flight modes. Input units are in feet.
33:	Vertical height from ground plane to heliport. This input refers to the heliport height above the basic ground level. It is required so that proper ground effect corrections can be made. It should be noted that the pressure altitude, temperature inputs, Locations 25 and 26, are referenced to the heliport as the datum. The potential energy also is based from the heliport level datum. The input is always positive and in units of feet. Heliport datum is assumed to be 0. if not input.
34:	Use 1, for free flight operation, -1., if rotorcraft is restrained before takeoff. This input is generally a (1.) which refers to free flight operation. It is used in determining the initial power required. If the aircraft is restrained, tied down, the (-1.) input will permit using maximum power (thrust) (without translation motion) at the first time point. This is useful for analyzing "bear trap" type takeoffs from ships on the high seas. This input will default to 1. if not input. No units.

Input Location	Definition
35:	Maximum allowable C_T/σ permitted furing flight. This input does not affect the analysis but is used for printing out a warning message if it is exceeded. C_T/σ is a criteria in determining blade life cycles. A default value of 0.15 is used if not input.
36:	This input location is reserved for internal use only.
37:	Initial power required. This input refers to the power required for the initial flight condition. If this value is not known put in an excessively high value. If input Location 34 is set to (1.), the program will compute the power required and use the lower of the two values. If Location 34 is set to (-1.), the program will use the horsepower input in this location provided it is greater than the calculated power required.
38:	Initial rotor tip speed. This input refers to the rotor tip speed at the start of the flight. It is input in percent referenced to the design tip speed of the helicopter in question.
39:	Initial longitudinal tip path plane angle. This input allows the user to input the longitudinal tip path plane angle for the initial flight point. If a (0.) is used the program will compute the tip path plane angle required assuming a steady-state flight condition exists. Input units are in degrees.
40:	Initial lateral tip path plane angle. If the lateral tip path plane angle for the initial point is known it can be input in this location. If a (0.) is used, the program will assume a linear flight condition exists for calculating the initial stabilized condition. Input units are in degrees.
41:	Initial rotorcraft heading. The initial heading (angular direction) from a given reference point can be input in this location. It should be noted that all turns analyzed in the computations are based on an angular displacement from the pre-existing heading. The input units are in degrees.
42:	Wind. The wind velocity occurring during the flight is input in this location. This velocity is assumed to be constant for the duration of the flight. It is input in knots.

Input Location	Definition
43:	Wind direction (measured from nose of rotorcraft). The angular direction of the wind is input in this location. It is always referenced to the nose of the rotorcraft, independent of the initial rotorcraft heading. The angular direction is measured clockwise when looking down on the rotorcraft. Thus a wind direction of (+10) will be coming in on the right side of the ship. A (-10) or (350) will be coming from the left when sitting in the cockpit. Input units are in degrees.
44:	Wind inclination from horizontal (positive down). This input refers to the wind direction off the horizontal plane. Zero (0.) degrees is assumed to be horizontal. An updraft will be (-90.), a down draft (+90.). Input units are in degrees.
45:	Autorotative entry, collective time delay. The time delay prior to corrective collective stick action after a sudden engine malfunction is input here. The input units are in seconds. See input locations 241 - 260 for further applications.
46:	Longitudinal control, time delay. The time delay prior to corrective longitudinal control action after a sudden engine malfunction is input here. It does not have to be the same time delay as the collective hold. Input units are in seconds.
47:	Lateral control time delay. The time delay prior to corrective lateral control action after a sudden engine malfunction is input in this location. The value used is independent of Locations 45 and 46. Input units are in seconds.
48:	Autorotative entry recovery rpm. The user can regain control of the rotor rpm by specifying that rpm in (%) in this location. The program sequencing will not occur until the collective time delay is completed and the rotor rpm is increasing. The program will return control to the user when this rpm is reached, provided the rpm went below this desired condition or the condition specified in the next event sequence is reached. See input Locations 51-60 and 61-70. The first condition to be satisfied will predominate. Input units are in percent.

Input Location	Definition

FLIGHT CONDITION PHASES

49: Number of events desired (10 maximum). The flight path analysis can be conducted for up to 10 separate events to occur. An event is defined as a specific condition to transpire between stated end points.

Example: Accelerate from 30 knots to 50 knots, when 50 knots is reached climb 100 feet, then make a 45^{o} left turn. This is three events:

1. Accelerate 30 - 50 knots
2. 50 knots - 100 feet
3. 100 feet - 45^{o} turn

See input Locations 51-60 for the available options.

50: Type of flight. The basic program is general in nature and was designed to handle the four basic flight modes.

Example: takeoff, rejected takeoff, landings and balked landings

Autorotations generally fall into the landing category although they can be entered from any of the four basic modes. For maneuvering flight prior to autorotative entry the takeoff mode should be used. Autorotation will be entered during the event in which the power available is set to zero (0.). See the appropriate sections 3.1-3.5 for more details on these flight modes.

The program requires a minimum of a 30 percent reduction in power to establish an engine malfunction. For partial power losses this assumption can be overwritten by adding the event number/10., which the engine malfunction is to occur onto the flight type. Thus if an engine malfunction is to occur during the third event of a takeoff the input would be 1.3.

Input values:

-2.	EMP Event/10 - Landing
-1.	EMP Event/10 - Rejected takeoff
1.	EMP Event/10 - Takeoff
2.	EMP Event/10 - Balked landing

Input Locations	Definition
51-60:	Event Options. These input locations permit the selection of any of five conditions which the program keys on for determining the end of an event. The program will sequence into the next event when the corresponding input in Locations 61-70 are met. Their main purpose is to establish the units for the values in Locations 61-70. The available options are

Input values:

-2. horizontal speed (kt) - Changes to next event when reached. The input in Locations 61-70 and 71-80 for the event number using this option must be identical. Velocities can increase or decrease from event to event.

-1. horizontal distance (ft) - Program interprets this option as the change in horizontal distance from the aircraft location at the start of the event.

0. time (sec) - The program interprets this option as the time duration of the event.

+1. vertical height (ft) - use of this option will sequence events when this wheel (skid) height is reached. If program is in takeoff mode and previous events have put the aircraft above the input value, the input is interpreted as a delta and added to the height at the start of the event.

+2. angle of turn (deg.) - This option always assumes the angular change from the aircraft heading at the start of the event. It should be noted that the sign convention used is positive (+) for a right turn, and negative (-) for a left turn.

It should also be noted that during autorotative entry the input used in Location 48 can override all of these options.

No restrictions are imposed by variations in event option sequencing. However, the user must exercise realism in the selection of the last event option and its value (e.g., don't land 20 ft. above the ground).

Example; Any random order of these five options can be use.

Input Location	Definition
61-70:	Desired condition at end of event. For the number of events selected in Location 49 the conditions desired at the end of the event are input in these locations. The values and units must coincide with the options selected in Locations 51-60.

The next block of inputs refers to the conditions that are desired to occur during each event. The program will work within the ranges specified but will not necessarily use the limit values if conflicting limitations are imposed.

Example: If the user specified a speed change of 10 knots with a maximum tip path plane angle of 20 degrees in 3 seconds. The program will start the tip path plane phasing at the rate specified but will phase back this angle at a time necessary to yield a smooth transition to the specified stabilized speed condition.

When an end of event condition is reached the next event will start from the velocity, rotor rpm and tip path plane conditions which the aircraft was at, at the end of the last event.

The inputs required in this section are:

71-80: Desired velocity at end of event (knots). The input velocities always refer to airspeed. They do not have to be sequentially increasing or decreasing. The only limitation imposed is: if the end of event option specified a speed, the input in this location must match the input in the corresponding location in block 61-70.

81-90: Desired power at end of event (SHP). This input refers to the maximum engine power that may be used during each event. If a (0.) is used in this location the program will automatically switch into autorotation mode. Using a (0.) in Location 81 will assume the aircraft to be in autorotation with a stabilized descent rate at the start of the flight. If the power was set to (0.) in any other event and future events include a power input, the program will assume a power recovery is being attempted and the power will be utilized.

91-100: Time of power application (seconds). The time required to change the power levels as specified in 81-90 is input here. Failure to input a value in these locations will set a default value of 1. second.

Input Location	Definition
101-110:	Desired rotor RPM at end of event (%). The rotor speed (rpm) level to be used during each event is input in these locations. The internal use of this input is not applicable during the autorotation entry mode of flight.
111-120:	Time of rotor speed change during event (seconds). The time required to change the rotor speed levels during each event is input here. Failure to input a value will set a default of 1. second. Not applicable to autorotating entry.
121-130:	Maximum longitudinal tip path plane angle during event (degrees). These inputs allow the user to specify the limit of the longitudinal tip path plane range to use during each event. The program will work within this range (+/-) as necessary to satisfy the airspeed conditions imposed. The sign convention used is: a positive (+) longitudinal tip path plane angle will accelerate the aircraft to a higher velocity.
131-140:	Time to maximum longitudinal tip path plane angle during event (seconds). The time default value is 0 degrees to transition to the longitudinal tip path plane angle, Locations 121-130, is input here. A default value of 1. second is used in no input.
141-150:	Phase out speed for longitudinal tip path plane angle (% airspeed). A desired airspeed change can be specified to occur during each event. The program assumes this airspeed is desired as a stabilized condition, if it is reached. Based on this assumption the tip path plane angle must transition smoothly so as to be in a position to hold the stabilized condition. This input refers to the percentage of the speed difference between events at which the tip path plane angle will phase back to that required for the requested stabilized airspeed. The program will default to a value of 60% if this input is less than 20%.
151-160:	Maximum lateral tip path plane attitude during event (degrees). This input is utilized in the same manner as the longitudinal control (Locations 121-130). The main difference is the sign convention. For lateral control a positive (+) input will result in a right turn. If an event option of +2 is used the sign of the lateral tip path plane angle must be the same as the sign of the angle of turn requested for the event in the appropriate Locations 61-70. The sign of these inputs must also be coincident with the turn angle requested in Locations 171-180. Default value is 0 degree.

Input Location	Definition
161-170:	Time to lateral tip path attitude during event (seconds). The time to transition to the lateral tip path plane angle (Locations 151-160) is input here. A default value of 1. second is used if not input.
171-180:	Turn angle desired during event (degrees). This input refers to the angular change in aircraft heading from the direction the aircraft was going at the start of the event. The sign of this direction change must be coincident with the lateral tip path plane displacement (Locations 151-160) and with the direction imposed if used as an event option in Locations 61-70. Default 0 degree.
181-190:	Phase out turn angle. A desired aircraft heading change can be specified to occur during each event. The program assumes that this heading change remains constant once the requested displacement is reached. In order to do this the lateral tip path plane angle must be returned to a position which will hold the desired heading. This input refers to that percentage of the angular displacement at which the tip path plane will start to phase back to that required for holding the desired heading. The program will default to a value of 60% if the input value is less than 20%.

Input Location	Definition
191-200:	System mechanical efficiency (% total shp), η. This input refers to that percentage of the total engine power that is available to the main rotor. These inputs can be input as a function of tip speed ratio μ, $(V_H/\Omega R)$ or as a function of power level (C_P). Tail rotor power is included in η.

The following method is used for loading this data.

$f(\mu)$: $100.*\mu.\eta$

$f(C_P)$: $100000.*Cp.\eta$

Limitations: If data is loaded as a function of μ the first point loaded <u>must</u> be at $\mu = 0$.

If data is loaded as a function of C_P, the first point loaded <u>must not</u> be at Cp of 0. If locations are left blank or 0.'s inserted the program will assume all the power is available to the main rotor and use a value of 1. If data is loaded a minimum of 2 points must be loaded.

Sample loading: $\mu = 0$ $\eta = .85$, $\mu = .3$, $\eta = .91$

Load 0.85 30.91

$C_p = .00015$ $\eta = .85$, $C_p = .0006$ $\eta = .91$

Load 15.85 60.91

201:	Fixed power losses (shp). This input permits accounting for power losses which are not a function of power level or forward speed. Items in this category would be generators, oil coolers, tach generator drives or any other accessory drive unit attached to the transmission gear train which reduces the power available to the main rotor(s).

Input Location	Definition

PROGRAM OPTIONS

202: Height-velocity avoidance. The Helicopter Dynamic Performance Program was designed to permit the user to have full control of 'control input'.[1]

Example: power, rotor rpm and tip path plane angles

At times this full reign of control can present problems, especially if a prescribed flight path is to be followed. The use of this input provides the user with a means of stating the height-speed (horizontal) relationship along with a tip path plane attitude range and the program will determine the power input required to follow the prescribed path. This assumes that sufficient power is available to follow the path.

The basic flight path that can be prescribed is built into the program and represents a typical lower limb of a height-velocity (H-V) curve. The user only needs to specify the 'nose' point coordinates of the (H-V) curve to establish the flight path.

Set this input location to (1.) to use this option. This input is only valid for the first event of the sequencing. Input location 50 must be set to (±1.) to use.

203: Critical speed on H-V envelope (knots). This input refers to the horizontal velocity at the 'nose' of the H-V curve to be analyzed. See Figure 1. If this input is less than 1 knot, the program will switch off the option switch in location 202 and treat the run as a normal takeoff.

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[1] The context used herein for 'control inputs' is the normal pilot reference of rotor rpm, horsepower (torque) levels and airframe attitude. No reference to actual stick positions is intended.

Input Location	Definition
204:	Critical height on H-V envelope (feet). This input refers to the vertical height at the 'nose' of the H-V curve. See Figure 1. This height must be greater than the initial hover height of the rotorcraft.

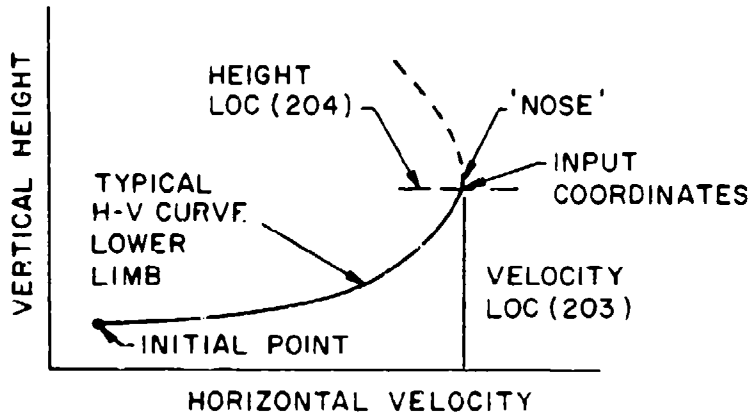

Figure 1. Critical height on H-V envelope.

205:	Horizontal takeoff procedure. This option is similar to the H-V option. The main difference is that the power level is specified and the program computes the tip path plane angle required to maintain a constant height during the first event of the sequence. Set location 205 to (1.) to use option. Input location 50 must be set to(± 1.)to use this option.
206:	Delta horsepower for horizontal procedure (SHP). This input is used in conjunction with location 205. It permits the user to specify the power increment above the power required for the initial condition to use for the first segment. If the calculated power required plus this increment exceeds the power input in location 81, the power level specified in 81 will be used.
207:	Auxiliary power units. If the rotorcraft being analyzed is equipped with an emergency power unit, this unit can be turned on during any of the ten events. The method of loading is: divide the event number desired, for ignition or starting of power unit, by 100 and add it to (1.). Example: to turn the unit on during event number 4 the input would be (1.04).

Input Location	Definition
207 (Cont'd)	This input location can also be used for analyzing rotor tip rockets. The method of loading for this option is: divide the event number desired for ignition by 100 and add to (2.). Thus, to turn the rockets on during event No. 3, the input would be (2.03). NOTE: Either auxiliary power units can be used or tip rockets can be used. They <u>cannot</u> be used together.
208:	Horsepower available from auxiliary power units (SHP) this input refers to the horsepower available from the auxiliary device(s), if Location 207 is set to 1.XX. If tip rockets are being used, 207 = 2.XX this input refers to the thrust output of each rocket. The program assumes that there is a rocket mounted on each blade and they are mounted at the tip of each blade. The thrust can be adjusted externally by the ratio: Input Thrust = Actual Thrust * Radial Location/Blade Radius if the rockets are mounted inboard of the blade tip. The rotor inertia, input Location 5, should be adjusted to reflect the weight of the rockets.

The inputs in Locations 209 and 210 infer tip rockets as auxiliary power devices.

No benefit in airfoil performance is assumed due to the presence of tip rockets. Any rotor performance improvement do to modified tip vorticies could be outweighed by the rocket drag penalties (function of rocket shape, location, etc.). Any such gains would have to be analyzed on an individual basis and could be reflected in the Delta-C_{L_M} coefficients if known. See input locations 221 - 224.

Input Location	Definition
209:	Delay time prior to ignition (seconds). In emergency situations airworthiness standards generally require a delay time to show compliance. These delay times and their impact on the flight profile can be evaluated by running a range of delay times. The delay time to use is input in this location.
210:	Time auxiliary power is available (seconds). Auxiliary power devices have been developed in various forms. These range from fuel driven 'APU' engines to propellent-driven turbines geared into the main transmission or the tail rotor drive shaft. The input here refers to the time (in seconds) that the power from these units is available to the main rotor. The program will use this power, for the stated time period, from the ignition start point, independent of the event sequencing during the burn period. It should be noted that 'APU' units may not be appropriate if the cause of main engine malfunction was due to contaminated or running out of fuel, unless the 'APU' unit has it's own separate fuel source.
211:	Mass moment of inertia of flywheel (ft-lb-sec^2). Provisions have been made for incorporation of a flywheel. If a flywheel is being used, its mass moment of inertia about the axis of rotation is input in this location.
212:	Rpm ratio of flywheel to main rotor rpm. If a flywheel is being used it can be located at any point of the rotorcraft drive train. Various points of the drive train operate at different rpm's,thus the rpm of the flywheel will depend on its location in the drive system. The input required here is the rpm ratio between the flywheel and the main rotor. Example: flywheel rpm/main rotor rpm The program will assume that a flywheel is not being used if Location 211 or Location 212 is input as (0.).

Input Location	Definition
213:	External propulsion units or inflight configuration changes (no units). This input provides the user with options to analyze the effects of external propulsion units such as jet assist takeoff (JATO) or rocket assist takeoff (RATO) units which are strapped to the airframe. Inflight configuration changes can also be activated by use of this switch. The manner of input is similar to that of Location 207. Example: If the option is to be used, the base input is (+1.XX) for use of external propulsion units, and (-1.XX) for configuration changes. The (.XX) refers to the event number (divided by 100) for which the option is to be envoked. Example: Drag brakes are to be deployed during event 5. The option switch would be input as (-1.05).
214:	Delay time prior to external propulsion unit ignition or configuration change (seconds). To comply with airworthiness standards, delay times are generally required. The delay time to be used is input in this location. This delay time is interpreted as from the start of the event for which the option is desired.
215:	Burn time of external propulsion units (seconds). This input refers to the time that thrust from the 'JATO' or 'RATO' units is available. It is only appropriate if the option switch (Location 213) is set to (+1.XX).
216:	Thrust per unit or configuration weight change (pounds). If the option switch (Location 213) is (+1.XX),this input refers to the thrust available from each of the external units used. The program assumes that the resultant thrust direction (from these units) goes thru the airframe center of gravity (cg). If the option switch (Location 213) is (-1.XX),this input refers to the weight change of the rotorcraft. This weight change can come about by either dropping an external load or picking up an external load. If a load is dropped the input is negative, conversely if a load is picked up the input is positive. The weight change is assumed to be immediate at the time of change.

Input Location	Definition
217:	Mount angle of auxiliary propulsion units (degrees). If external thrust units are being used, the angle (off vertical) that these units are mounted to the airframe is input in this location. A mount angle of (0.0) degrees assumes the total resultant thrust is straight up. This input does not apply for the configuration change option.
218:	Number of external propulsion units or change in airframe (F) (-, sq. ft.). If external propulsion units are being used the number of units being used is input in this location. If a zero (0.) is input or this location left blank, the program will assume no (0.) units are being used. If the input in Location 213 is set for configuration change option (-1.XX) the change in airframe F due to the configuration change is input here. Examples: 1. External load of 1,000 lb to be dropped during 4th event. A time delay of 1.5 seconds is to be used. The external load has an F of 10. sq. ft. Input Location 213 set to (-1.04) 214 set to 1.5 216 set to -1000. 218 set to -10. 2. Drag brakes to be deployed during event 5. A 1-second delay is to be used. the drag brakes have an equivalent 'F' of 12 sq. ft. Input Location 213 set to -1.05 214 set to 1.0 216 set to 0.0 218 set to +12. 3. Two external propulsion units are mounted at a 60° angle (from vertical). Each unit has a rating of 1,000 lb thrust. A 2-second delay time is to be used. Ignition is to occur during the third event. The external units have a burn time of 15 seconds. Input Location 213 set to 1.03 214 set to 2.0 215 set to 15.0 216 set to 1000. 217 set to 60.0 218 set to 2.0

Input Location	Definition
219:	Supplementary output file and Cal-Comp plot file stop switch. Due to the large volume of program output, a supplementary store file had to be used in the program development. This input location provides the user with the option to select the file number. Any file unit number can be used between 9 and 26 provided it does not conflict with input Location 220. The program will default to unit 10 if not input.
	The supplementary hard copy output can be suppressed by setting this input value to a negative number.
	For batch processing with Cal-Comp plots, this number must be set to the unit number +.1 on the last case to be analyzed. This insures getting an end of file mark on the cal-comp output tape.
220	Basic print file output unit, plot option. The basic program output is stored internally. The print file from which the hard copy is to be printed is input in this location. This print file can be any unit number between 9 and 26, provided it does not conflict with Location 219. The program will default to unit 6 (standard printer unit) if location is not loaded.
	The basic output time history can be suppressed by inputting this value as a negative number. The resulting output will be a summary of the flight. This summary only contains the conditions that prevailed at the start of each event and the conditions at flight termination.
	Output diagnostics are also included on this summary.
	This input location also provides the plot options. This option is switched based on the number after the decimal point on the unit number. Four options are available.
	1. Nu.0 No plots requested.
	2. Nu.1 Interactive plots, TEKTRONIX and Cal-Comp format.
	3. Nu.2 Interactive plots, Cal-Comp format only.
	4. Nu.3 Batch processing, Cal-Comp output only.
	Interactive plotting is self explanatory by on-line prompting. Batch process plotting can be tricky. Refer to Sections 5.0 and 5.3 for batch process plot output before attempting this mode.

Input Location	Definition
221-224:	User δ-C_{L_M} coefficients (cubic). The basic airfoil data for the main rotor is represented as a mean profile drag coefficient and mean lift coefficient polar. These polars can generally be represented as a cubic equation. The basic equation form is $\delta = AC_{L_M}^3 + BC_{L_M}^2 + CC_{L_M} + D$ The inputs in these locations refer to the equation coefficients A, B, C, and D, where Location 221 = A, 222 = B, etc. The program has the basic 0012 airfoil section polar built in. If the user does not specify a lift-drag polar in these locations the program will default to using the internal 0012 section data.
225:	This input location is reserved for internal switching arrangements. <u>DO NOT USE</u>.
226:	To account for winged helicopters, the location of the wing with respect to the main rotor head is required. If a wing is being used, the horizontal distance from the main rotor center line to the wing ¼ chord point is input in this location. The input is in inches and is positive if the ¼ chord point is aft of the main rotor. Use forward rotor for tandems.
227:	The vertical distance from the main rotor centroid to the wing chord line at the ¼ chord point is required in this location. The input is in inches and is positive if the wing is below the rotor. Use forward rotor for tandems.
228:	Wing span. The program assumes the wing span as measured tip to tip. The input is in feet.
229:	Wing chord. The wing chord input is input as measured at the three quater (.75) semi-span. The input units are in feet.
230:	Wing taper ratio. The wing taper ratio is input as the tip chord/root chord. No units.

<u>NOTE:</u> Analysis of winged helicopters is currently not available.

Input Location	Definition
231:	Optimization Switch:

An input of 1.X in this location will activate the optimization routines. The .X allows the user to optimize any one or all of the three critical points on the height velocity diagram, i.e., low hover height, nose point, high hover height.

A -1.0 Estimate the H-V envelope only
1.0 Will optimize all three (3) points.
1.1 Will optimize the low hover height only.
1.2 Will optimize the nose point only.
1.3 Will optimize the high hover point only.
1.4 Will optimize for maximum range in auto-rotation.

When using this option, a list of the inputs required for obtaining the optimized time history results will be printed on the output file. This listing is provided as inter-active; use of the program is not recommended due to high computer run times. These listings can be used to reload the case to get the inter-active plots.

The user can plot the pertinent data after all optimization is completed. Thus if the 1.1 option was selected, the data for the low hover height will be available for plotting. If the 1.0 option is selected, the basic plot data will be for the high hover height although the height-velocity diagram will reflect the optimization of all three critical points. The 1.1 option H-V diagram will only reflect the optimized low hover height. This condition also prevails for the 1.2 and 1.3 options. The non-optimized points reflected on the H-V diagram drawn only reflect the estimated starting points used for optimizing.

A 2. VV@EMP/1000 input will calculate the horsepower requirements at the EMP for the specified vertical velocity. Caution: The use of this option will override the horsepower input in location 80 + event No. @ EMP. For subsequent cases the user must re-load the original horsepower value in the appropriate location. VV is in ft/min.

This option(2.VV/1000)can not be used in conjunction with the 1.X options.

See Section 6 for details on optimization routines and minimum input requirements for H-V optimizing.

Input Location	Definition
232:	Desired vertical touchdown speed (ft/sec). This input allows the user to specify the maximum vertical touchdown speed allowed for the flight condition. This input is used for the rejected takeoff, landing, autorotation and optimization modes. If user fails to input a value in this location, a velocity of 3 FPS will be assumed. A tolerance of +0.5 FPS is used.
233:	Remaining engine power after engine malfunction. This input provides the capability of evaluating H-V envelopes for multi-engine rotorcraft after a single engine malfunction. If user fails to input a value in this location, the program will assume a total power failure with 0 power remaining.
234:	Min - Max horizontal touchdown speed. This input refers to the allowable range of horizontal touchdown speeds to be used in the optimization of the H-V envelope. The input is made as min speed. Max speed/100. Units are in knots and ground speed is assumed. If user fails to input the values, the program will assume a 0. - 15. Kt. range is allowable. The program will accept as a solution the touchdown speed within the input range to maximize the H-V solution provided the other constraints of touchdown vertical velocity, body attitude and rotor RPM are also met. The user can minimize the H-V restrictive area by "squeezing" in the allowable range for acceptable solutions. The minimum input value for specifying the maximum speed must be at least .001 to override the default.
235:	Min-Max body attitude at touchdown. This input specifies the minimum and maximum allowable body attitude at touchdown. It is used only in the optimization routines of the program. The input units are in degrees. The defaults are 0 and 12 degrees if not user specified. The input is made as Min angle. Max angle/100. The user can minimize the H-V restrictive area by "squeezing" in the allowable range for acceptable solutions. The minimum input value for specifying the maximum touchdown attitude must be at least 0.001 to override the default.
236:	Max-Min touchdown RPM. This input specifies the maximum and minimum allowable touchdown RPM. The input is made as % Max RPM. % Min RPM/100. The input units are in % of design RPM. It is used for all landing or rejected takeoff flight modes. Default values are 120 percent maximum, and 50 percent minimum if not user specified (e.g., 120.50). For partial power conditions the maximum value is set to 3 percent greater than the speed selector N_R as specified in input Location 38.

Input Location	Definition
236: (Cont'd)	This 3 percent is used as the typical fuel control bias of current technology turbine engine fuel controls. This N_R must be reached prior to any power reduction from the remaining engine(s).
237:	Vertical height for program control during landing maneuvers. The basic HDP program provides an over-ride control for adjustment of collective (Θ_{75}) and/or shaft horsepower to attain the vertical impact speed specified in Location 232. The wheel (skid) height at which the user desires the program to override the control input values in Locations 101, 120, and 241-260 is input in this location. If user does not specify this value, program will default to 20 ft. For override option to activate: 1. the vertical height must be at or within threshold given by Location 237, and 2. the vertical speed must be within desired touchdown speed, ± 2 fps, given by Location 232. The user can bypass this option by inserting a negative number in this location.
238:	Min. Max. Theta 75 limits. This input refers to the minimum and maximum collective control limits in degrees. If user does not input values, a minimum setting of 0 degrees and a maximum of 18 degrees will be used. The program will not allow these values to be exceeded. Input as Min Θ_{75}. Max Θ_{75}/100.
239:	Rotor disc lift curve slope. If not known, leave blank or set to 0. Refer to engineering report section on disc theory lift curve slopes.
240:	Theta 75 required for initial conditions. If the Theta 75 required for the initial flight conditions is known, user can input that angle in this location. The program will compute the rotor disc lift curve slope based on this input. The input is in degrees. If this value is not known, leave location blank or input a 0.

It is recommended that if the disc lift curve slope is not known, a short duration flight be run with the initial conditions for a known Theta 75. After the run, interrogate loader Location 239. The number in this location is the disc lift curve slope for the aircraft in question. Then load this value into the base file for Location 239 and reset Location 240 to a 0.0.

Input Location	Definition
241-250	Delta Theta 75. These inputs refer to the desired changes in Theta 75 for each event. These changes are added to the Theta 75 angle at the start of each event thus are accumulative. A Delta Theta 75 value of at least +.0011 must be used to activate this option. If the option has been turned on, the user can turn it back off with an input of -100.

Caution: If the user has turned the option on and fails to turn it back off, the program will assume a 0. Deg Theta 75 change is desired if the user fails to load these data for each event.

Example

Event	1	2	3	4	5	Cond.
Input	0.	0.	.0011	0.	0.	A
Starting	0.	0.	.0011	-100.	0.	B
in 241	0.	0.	.0011	- 10.	15.	C

Events 1 & 2 are based on input N_R schedule

Results:

A: Theta 75 will be held fixed from event 3 - 5.
B: Theta 75 will be held fixed for event 3 only. Events 4 & 5 will be based on input N_R schedule.
C: Theta 75 will be held fixed for event 3 decreased 10° or to minimum allowed during event 4 then increased 15 deg. from the starting point of event 5.

251-260 Time rate of collective input. These inputs provide the user the capability to specify the rate of Delta Theta 75 application. The program will assume a 1 sec. rate or a maximum of 15 deg. per second if user fails to load this data.

When the autorotation entry mode is used in conjunction with these inputs, the value used for time when Delta Theta 75 is set to .0011 must also be loaded in location 45 to retain continuity.

Input Location	Definition
261-297:	Reserved for future development.
298:	Airframe pitch damper. The basic HDP analysis does not consider body aerodynamics other than the body drag forces. Thus analysis of airframe pitch attitude with respect to the rotor tip path plane attitude requires a damping term. Typical values for articulated rotors are 0.4 to 0.6, teetering rotors have displayed values of 0.05 to 0.2 as typical. Input values in these ranges should be used and comparison with flight test data made to establish a representative input value for the aircraft in question. Input range is 0.0 to 1.0.
299:	Airframe roll damper. This input is used in the same context as location 298. Except it applies to the roll axis. Typical values and verification procedures are also the same.
300:	User input flight time limit. The HDP program was designed with a data storage capacity of 300 points per output variable. This permits a maximum flight time of approximately 150 seconds. At times, due to an error in the input data, a flight which would normally take 15 to 20seconds will go to full storage capacity trying to satisfy the inputs. This input location provides the user with the capability of limiting the amount of flight time allowed,thus minimizing the computer time required to find out that the input might be in error. The user input is used as maximum flight time allowed. The program will stop all calculations when this flight time is reached and call the plot package or return for more input data. Maximum storage limitations will be used if user does not input a value. The input, if used, is in seconds.

2.2 LOADING INPUT DATA

The input requirements described in Section 2.0 and/or 2.1 are loaded into the program at execution time in the following manner. It should be noted that only the first case of a given run need load the complete input requirements. Input data can be loaded in 'shot-gun' form.

i.e., No firm order of input need be adhered to. Each input or string of inputs is assigned a location number and may be loaded singularly if desired.

The loader format is FREE FIELD. That is to say that the numbers can be placed in any card column(s) up to column 72. The only qualification between different numbers is that they be separated by a blank space or a comma.

The first number on the card <u>must</u> be the number of inputs to be read. The second number must be the input location for the next number on the card. A typical input card would be N L P_1 P_2 P_3 -- P_N or N, L, P_1, P_2, P_3 -- P_N

Where: N is the number of values to be loaded on the card (36 maximum).

L is the input location of P_1.

P_{1-N} is the numerical values of the input.

If the user is interactive with the program, the input of the letter T in column 1 of any card will alert the program that the user is on line and if input errors occur allow the reinput of the card. <u>Do not</u> input a "T" when operating in batch mode.

A minus (-) sign prefixing N of any loader card will cause the program to start calculating the case after the card is read.

After the case is calculated, the program will return to loader to pick up new case data.

For subsequent cases, only the input locations desired to be changed need be entered. Any unchanged values will remain as previously loaded.

If any input value is changed between cases, it will remain in common as the last value loaded.

For the HDP program the run will terminate if location 1 is a -1. or location 219 has a (.1) after the supplementary file unit number.

Insertion of Title Cards

The HDP program has been set up to permit the insertion of one card of 24 alpha-numeric characters (the first character must be blank). This can be done by specifying the number of blades, input location 1, to a non-integer number. If this input is specified as non-integer, i.e., 2.1 blades, the program will expect a title card after all loader data has been read. The program will reset the number of blades to the integer value for calculations. Subsequent cases will not expect a title card until the user respecifies the number of blades as non-integer.

Review of Input Data

The input data vector can be reviewed after the first case prior to calling for new loader data. At the end of each case, the program will ask if review is desired with the message: REVIEW DATA, A 0 input will bypass the option.

A 1 input will allow the user to review any specified loader range for reviewing, i.e., if loader locations 1 - 100 want to be reviewed, a key in of 001100 will retrieve this data and display it to the screen.

CAUTION: Do not key in any value greater than 300, the maximum length of the vector.

This option is only available in inter-active mode and will not interfere with batch processing.

3.0 A GENERALIZED APPROACH TO TAKEOFF AND LANDING PROBLEMS

While the analysis of takeoff and landing problems cannot be categorized into one specific procedure to cover all possible questions, a generalized approach for establishing takeoff and landing operational capabilities is outlined herein.

Before any analysis of operational capabilities can be conducted a thorough understanding of the pertinent safety-of-flight regulations is required. Since these regulations will vary, depending on heliport size and location, it is recommended that the pertinent document(s) be referred to for the specific situation being investigated. A list of applicable documents is given in Section 3.6.

In order to establish basic procedures for evaluating operational capabilities the regulatory requirements were reduced herein to reflect their basic content. In view of this, the following notes generalize actual situations so as to avoid the confusion of minute details. Consequently, these notes should not be applied to specific instances without further exploration into those sometimes meaningful details.

3.1 TAKEOFFS

Takeoff procedures can be classified into three basic categories.

1. Vertical Procedure
2. Oblique Procedure
3. Horizontal Procedure

Basic flight paths for these procedures are shown in Figure 2. For establishing operational weight capabilities these profiles are predicated on sustaining an engine malfunction during the takeoff. For multi-engine rotorcraft the point of engine malfunction (EMP) is referred to as the Critical Decision Point (CDP) when the rotorcraft is at a speed and altitude from which:

a. The takeoff can be rejected and a safe landing effected within the heliport boundaries.

b. The flight can be continued and maintain:

   1. A clearance past the edge of the heliport of no less than (H_1) ft.

   2. The minimum height of the flight path yielding an obstacle clearance of no less than (H_2) ft.

   3. An obstacle clearance of no less than (H_3) ft. during the climb out.

The magnitudes of H_1, H_2, and H_3 shown in Figure 2 are dependent on the pertinent FAA or Military criteria.

The Distance (D_1) Figure 2 basically defines the paved field size requirements and is predicated on the point to point rejected takeoff distance plus the aircraft length. It should be noted that landing distances must also be considered in the determination of the paved field size requirements. This is discussed in section 3.3.

The distance (D_2) and (D_3) are basically a function of heliport location and must be considered when establishing the takeoff procedure and weight capabilities.

Determination of Takeoff Capabilities

One of the most common questions asked when a new helicopter design or heliport location is proposed is "What is the maximum takeoff weight capability for this situation?" The following outline shows a basic approach that can be used to be responsive to this question.

Initially, a series of trade-offs should be conducted to establish the takeoff procedure to use. These can be conducted independent of the pertinent regulatory requirements. The basic trade-offs, for establishing the takeoff procedure after EMP, are shown in Figure 3. From these data the takeoff safety speed, maximum tip path plane attitude, and minimum rotor RPM can be determined for minimizing the height loss after engine malfunction. The rates of tip path plane motion and RPM droop can also be traded off but must be maintained within realistic workload and structural limitations. It should be pointed out that while the manner in which the rotorcraft enters the EMP affects the magnitude of the height loss, the variations in ΔV_H, Max. αTPP and N_R will not be significantly affected.

With these basic procedures established the operating weight for complying with the regulatory requirements of H_1 and H_2 can be determined. The basic trade-offs for establishing the takeoff weight capabilities are shown in Figure 4.

The trade-offs shown in Figure 4 assume that the procedures for getting to the EMP are defined. The determination of the procedure to use is basically dependent on the available distances to the obstacles along the flight path. Charts can be set up for determining the distance requirements as a function of operating weight by varying the horizontal entry speed at the EMP.

One word of caution, when considering the oblique procedure the minimum climb out speed is limited by the ability of the airspeed system to accurately and repeatably indicate the desired speed. Present airspeed systems are not reliable below speeds of 20 knots, thus limiting the available climb out speed range.

These trade-offs basically establish a means of determining takeoff capabilities. Before any final solutions are reached their compatibility with rejected takeoffs must be investigated.

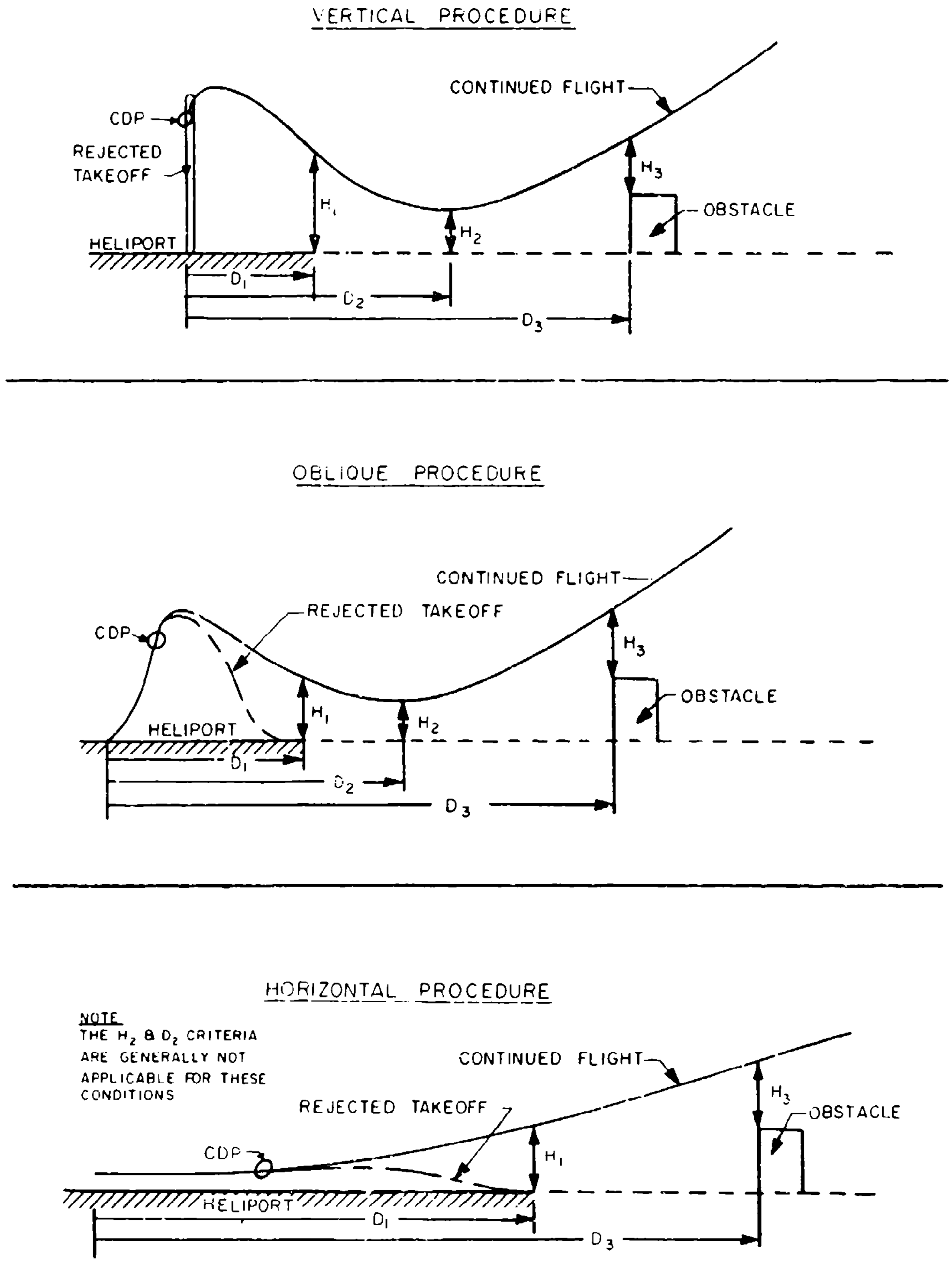

Figure 2. Takeoff procedures.

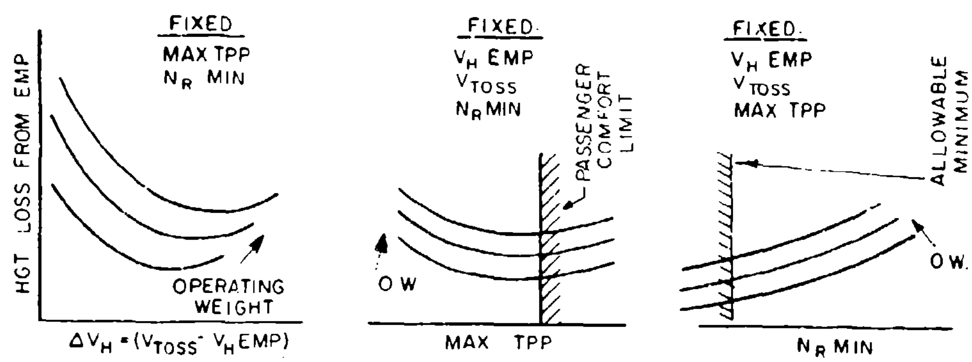

Figure 3. Basic trade-offs for establishing takeoff procedures.

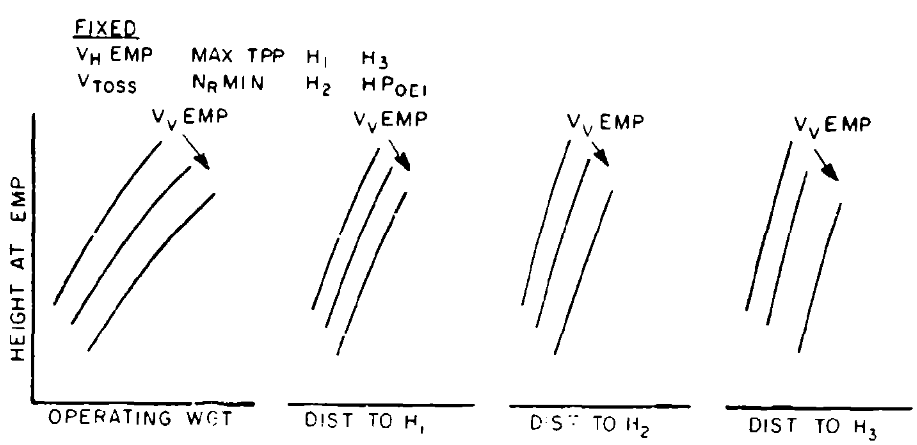

Figure 4. Takeoff operational envelope.

3.2 DETERMINATION OF REJECTED TAKEOFF CAPABILITIES

The analysis of rejected takeoff mainly concerns itself with establishing the operating weight with which a specified vertical touchdown speed can be maintained. This basically reduces the analysis to establishing a collective flare height for which a specified vertical touchdown speed can be met at a given operating weight. A basic trade-off for determining the operating weight is shown in Figure 5 (1). Conducting a series of these trade-offs will yield an operating envelope similar to that shown in Figure 6.

The Helicopter Dynamic Performance Program provides an option for automatically evaluating the trade-offs shown in Figure 5 yielding the operational envelope through the use of the optimizer option.

The analysis of rejected takeoff lends itself to a wide range of trade-offs, to maximize the weight, by applying a range of speeds at the collective flare point and touchdown point. These variations can be applied in turn to a range of entry conditions to the EMP. The main factor controlling the procedures used is the heliport size. Definable procedures are also a requirement when considering these trade-offs.

3.2.1 Determination of the Critical Decision Point

By definition the Critical Decision Point (CDP) is that point at which if the critical powerplant becomes inoperative a safe continued flight and a safe rejected takeoff can be conducted.

This point can be determined by superimposing the operational envelope developed for the takeoff condition with that developed for the rejected take-off condition. This overlay is shown in Figure 7. The intersections of the lines of constant vertical velocity at EMP defines the CDP and the maximum takeoff weight.

These intersection points should be checked with distance requirements to verify compliance. It should be noted that all weights to the left of the CDP are acceptable solutions. While these weights are less than the maximum it might have to be compromised to yield the distance requirements for the particular heliport and flight path obstacle locations. It should also be noted that the field size requirements are defined by the rejected takeoff distance. If the distance to the H_1 criteria on takeoff is less than the rejected takeoff distance, the aircraft must have a positive climb gradient as it passes the edge of the heliport to have a satisfactory solution.

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1 When conducting these trade-offs the procedure used before EMP must be identical to that used for the takeoff evaluation to maintain compatibility.

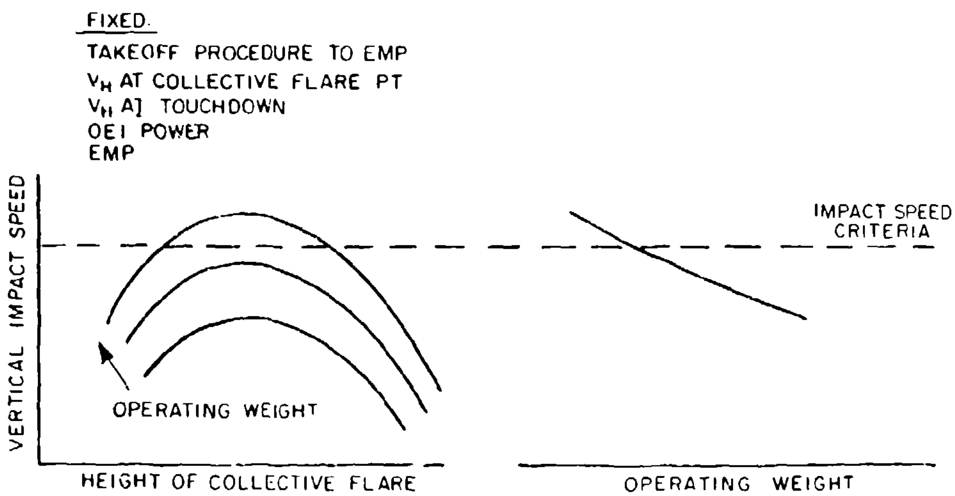

Figure 5. Basic rejected takeoff trade-off.

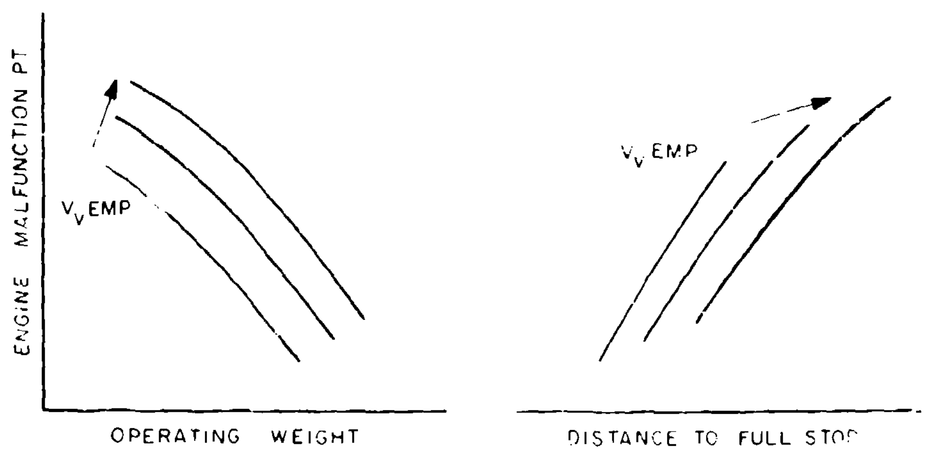

Figure 6. Rejected takeoff operational envelope.

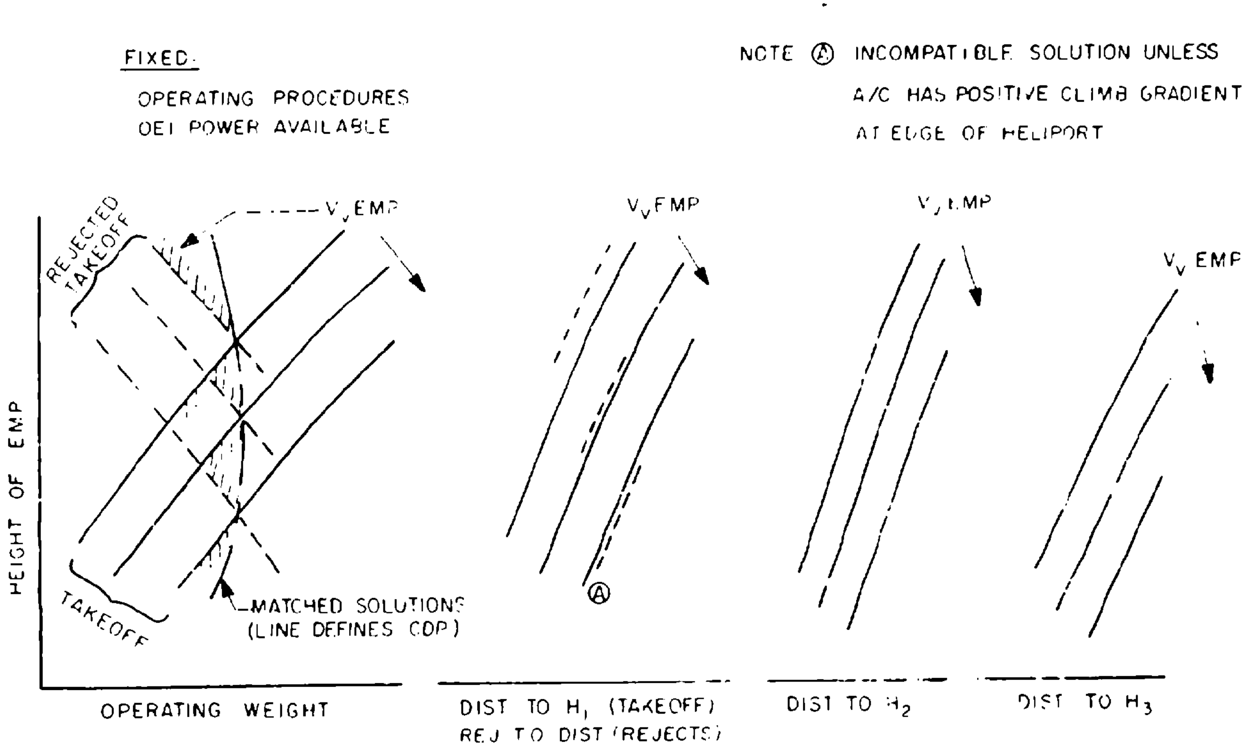

Figure 7. Determination of critical decision point.

3.2.2 Determination of Weight-Altitude-Temperature Curves

The procedures previously outlined deal with the basic methods for establishing the maximum operating weight for a given takeoff procedure. In doing this, the engine malfunction point and the vertical velocity at the EMP were used as variables so as to establish the CDP and maximum weight for a given altitude and temperature.

In establishing the maximum operating weight at various altitudes and temperatures, variations in CDP and vertical velocity at CDP will occur. While allowing these to vary will yield the maximum weight capabilities, the application of these variables for scheduling purposes, become operationally unfeasible. These variations also do not safely account for the conditions when the rotorcraft is not loaded to the maximum allowable operating weight for which the takeoff procedures were established.

To establish an operationally feasible takeoff procedure, which can be used for any Weight Altitude Temperature (WAT) combination, the following method is recommended.

The critical decision point, vertical velocity at EMP and maximum operating weight are established for a given altitude, temperature and basic procedure. This is referred to as the BASE procedure point. For operational practicality the CDP is held fixed for all WAT combinations. The vertical velocity at the CDP is utilized to the extent of determining the twin engine torque (TEQ) at the CDP. This vertical velocity is held fixed for all WAT combinations.

The steps to follow for each altitude and temperature being considered are:

1. Establish the Weight-TEQ relationship for the fixed vertical velocity at CDP. This appears as a curve 1 in Figure 8.
2. For 3 vertical velocities, establish the operating weight capability for safe rejected takeoff from BASE decision point. Curve(2)in Figure 8.
3. Compute takeoff at 3 vertical velocities, using BASE decision point, to obtain operating weights for safe continued flight. Curve(3)in Figure 8.
4. The operating weight for this altitude and temperature will be the lower of the two weights defined by the intersection of curves (1)and(2) or (1)and(3).

Computing in this manner over a range of altitudes and temperatures will then result in a WAT curve and TEQ schedule as shown in Figure 9.

The TEQ curve, shown in Figure 9, becomes an integral part of the takeoff procedures. The use of this curve basically establishes a fixed vertical velocity at the CDP and allows safe operations at takeoff weights less than the maximum allowable for the altitude and temperature. If the WAT curve is developed for a wide range of altitudes and temperatures, this curve might have to be compromised from the computed ideal conditions.

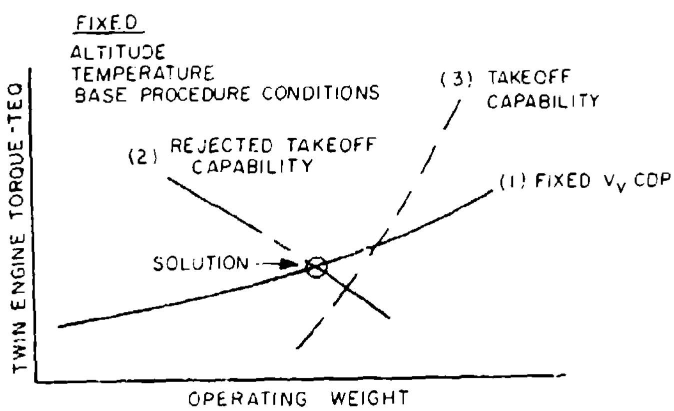

Figure 8. Determination of weight - altitude - temperature capability.

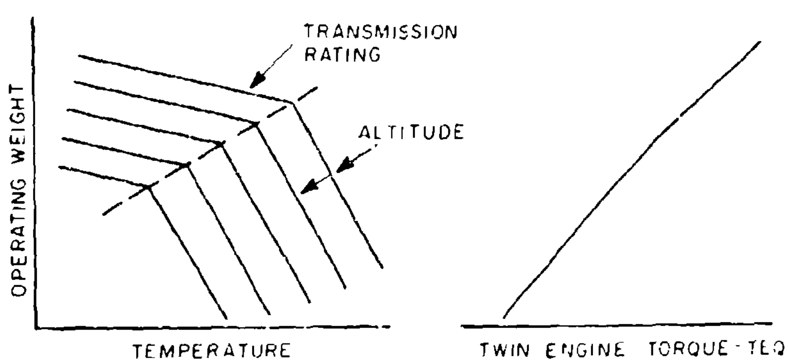

Figure 9. Typical weight - altitude - temperature curve.

3.3 LANDING AND BALK LANDINGS

Present commercial regulatory requirements do not permit landing weights in excess of takeoff weight capabilities. These conditions could exist considering a takeoff from a large heliport, permitting high takeoff weights, and landing on a small heliport which has a low takeoff weight restriction. In view of this, landings and balk landings are generally analyzed using the takeoff weight schedule for the smallest heliport on the proposed flight route.

On this basis, the analysis of landings and balk landings can be reduced to establishing the landing decision point (LDP). The LDP is defined as that point from which the weight, approach speed, and altitude are such that should the critical powerplant become inoperative:

a. The landing can be rejected, a balk landing conducted, and the flight continued with:

   1. The minimum height on the flight path yielding an obstacle clearance of no less than H_2 ft.

   2. The rotorcraft maintaining an obstacle clearance of no less than H_3 ft. during the climb out.

b. The landing can be continued and a safe landing affected within the heliport boundaries.

A typical landing profile is shown in Figure 10.

It should be noted that for landings a threshold clearance of H_1 ft. is generally specified. Also for landings the field size requirements are generally defined as the distance covered from the edge of the heliport (through H_1) to full stop plus the rotorcraft length all times 1.XX. Refer to applicable regulations for the multiplying factor 1.XX. Thus from Figure 10,

$$D = (D_1 + \text{A/C Length})\ 1.XX$$

The resulting landing distance must be compared with the rejected takeoff distance and the greater of the two used for establishing field size requirements.

3.4 BALK LANDINGS

When analyzing balk landings the flight procedures used after the LDP are generally the same as those specified for the takeoff. Thus the trade-offs conducted for takeoffs, Figure 3, are applicable to balk landings. With the basic procedures defined, a series of balked landings are computed for a range of landing decision points, vertical velocities at the LDP and a range of horizontal approach speeds. A typical trade-off for establishing balk landing capabilities is shown in Figure 11.

In conducting these trade-offs the required clearances for H_2 and H_3 should be investigated and the results should reflect the more demanding condition. The airspeed system readability and repeatability should also be considered when establishing the horizontal approach speeds.

3.4.1 Landings

The main concern when analyzing landings at a fixed weight condition is the landing distance required. Thus, the field size basically dictates the overall landing procedures. The item which mainly controls the landing distance is the horizontal roll on speed which in turn is governed by the allowable vertical touchdown speed. To establish the minimum horizontal roll on speed a trade-off similar to that shown in Figure 5 can be conducted. Since the operating weight is fixed, in this case, variations in horizontal roll on speed would be substituted for the operating weight variable in Figure 5.

Conducting this analysis for a range of LDP's, vertical velocities at LDP and horizontal approach speeds will yield a landing capability envelope as shown in Figure 12. The LDP's and approach conditions used for this analysis should be conducted at the same conditions as used for balk landings.

3.4.2 Determination of the Landing Decision Point

By definition the landing decision point (LDP) is that point from which if the critical powerplant becomes inoperative a safe continued flight or a safe landing can be conducted.

This point can be determined by superimposing the operational envelope developed for the balked landings with that developed for the landing condition. This overlay is shown in Figure 13. The intersections of the lines of constant vertical approach speed defines the LDP and required horizontal approach speed for the operating weight in question. The field size requirement and availability is the determining factor for selecting the LDP and associated entry conditions.

The means of determining the LDP outlined herein is based on the maximum allowable weight determined from takeoff capabilities. If the maximum landing weight is desired, trade-offs similar to those conducted for take-off and rejected takeoffs can be conducted. In doing this the LDP would be substituted for the CDP in Figures 7 and 8. The twin engine torque (TEQ) axis in Figure 8 would be replaced by the horizontal approach speed, and the TEQ schedule shown in Figure 9 would be deleted.

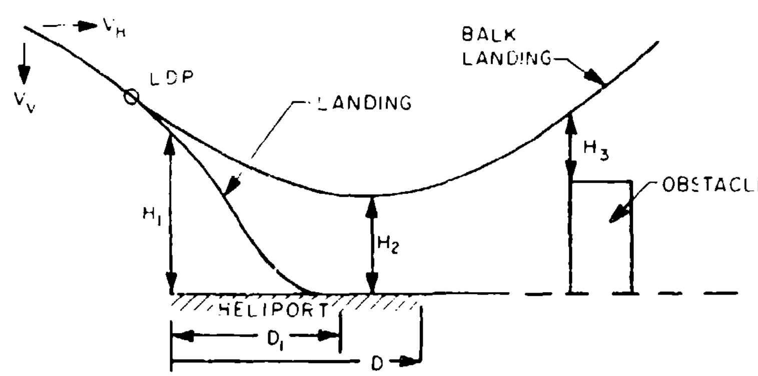

Figure 10. Typical landing profile.

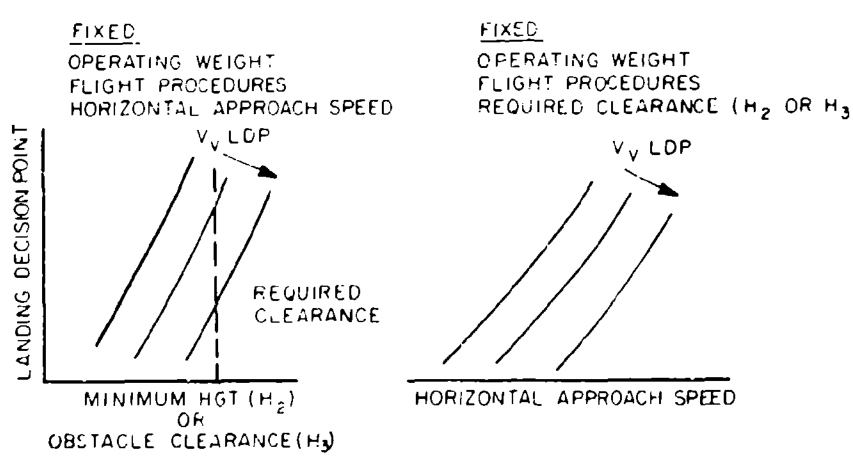

Figure 11. Typical balk landing trade-offs.

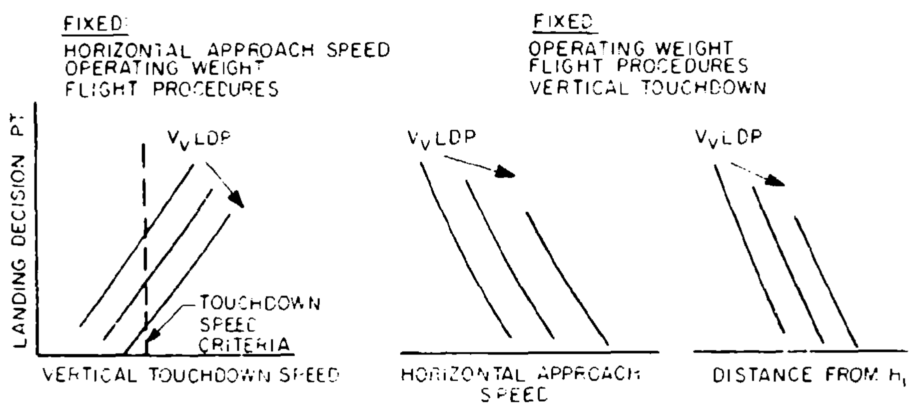

Figure 12. Typical landing trade-offs.

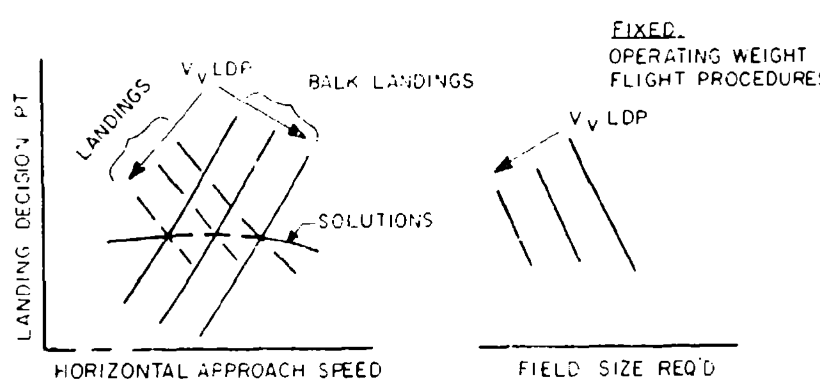

Figure 13. Determination of landing decision point.

3.5 AUTOROTATIONS

Analysis of autorotations basically involves the determination of the approach speed and cyclic flare height from which a safe landing can be affected. On this basis, the maximum possible weignt that could be achieved is when only one combination of approach speed and cyclic flare height exists. In actuality, this weight cannot be achieved as present instrument systems do not have sufficient accuracy for a pilot to repeatably attain this exact point.

To establish a maximum practical weight, a range of approach speeds and cyclic flare heights must exist from which safe landings can be made. This range of speeds and heights is referred to herein as the CYCLIC FLARE GATE. The magnitude of this cyclic flare gate must be such that a pilot can repeatably initiate the cyclic flare within the proposed boundaries. Consideration should also be given to the reading accuracy of the instruments involved when establishing the flare gate.

The following procedure outlines a means of determining the available flare gate for any specified operating weight.

Initially, a basic flight procedure should be established. Based on the typical autorotation flight path as shown in Figure 14 a basic flight procedure could be written as:

a. Establish stabilized autorotation with the collective stick adjusted to maintain (N_R) RPM at a horizontal approach speed of (Va).

b. At a vertical height of (Hc) apply aft cyclic to attain a nose up attitude of (α) degrees in approximately (t) seconds.

c. At a height of (H_F) feet apply forward cyclic to reduce the body pitch attitude to within acceptable touchdown limits and apply collective as necessary to minimize the vertical contact speed.

The terms, N_R, Va, Hc, α, t and H_F are independent variables in the analysis.

For the purpose of this outline let's assume that the values of N_R, α, t and H_F are specified. This reduces the analysis to the two prime variables of the cyclic flare gate, i.e., Va and Hc. Computing a series of autorotations for a range of these variables will yield the relationship of the vertical and horizontal touchdown speeds as a function of the cyclic flare heights and approach speeds. A typical trade-off of these results is shown in Figure 15 A cross plot of these results for specified vertical touchdown speeds will then yield the available flare gate envelope. A typical envelope is shown in Figure 16 Trade-offs with the N_R, α, t and H_F variables should be made to establish the maximum flare gate envelope. Realistic pilot work load structures should be considered in this evaluation.

The flare gate envelope shown in Figure 16 assumes that reasonable pilot corrective action was used during the landing. To gain some insight as to what corrective action is available, the events occurring during the cyclic flare transition should be understood. For this evaluation, typical time histories for three approach speeds at a given cyclic flare height were plotted in Figure 17.

Analysis of the 82.5 knot approach condition shows that the application of potential, kinetic and rotor energy, the only energy available in autorotation, was initiated and transferred at a rate which minimized the vertical velocity an instant before ground contact was made. This approach condition is optimum for the assumed procedure.

The 75-knot approach condition shows that using the specified control input rates and limits, insufficient knetic energy, is available and insufficient rotor energy was applied. This resulted in the inability to reduce the vertical velocity at the touchdown point.[1] With a pilot flying the helicopter, the high descent rate condition could be detected and more aft cyclic applied, along with earlier collective application, to obtain more rotor energy. These corrections would help minimize the vertical impact speed. Although this type of corrective action could be applied, the available kinetic energy level is low, due to the low forward speed, and higher approach speeds are recommended.

Analysis of the 90-knot approach condition, Figure 17, shows that more than sufficient energy is available. The higher initial forward speed results in higher forward velocities during the entire maneuver yielding a higher rotor lifting efficiency during the collective flare. Consequently, there is a larger rotor thrust available to reduce the vertical velocity. The time history, Figure 17 shows that the vertical velocity is reduced to zero before ground contact with a slight instantanious climb capability. The reduction in body attitude, required by the landing gear configuration, reduces the available kinetic energy level and the remaining rotor energy level is insufficient to maintain a low sink speed ,thus the rotorcraft "fallsthru" to a landing. Under these conditions this high pull out could be detected, with a pilot in the loop, and the cyclic and collective inputs adjusted during transition to minimize and possibly eliminate the "Fall Thru".

These are the basic types of corrective actions which can be assumed in the determination of the cyclic flare gate boundaries. While the actual determination of these boundaries is left to the discretion of the analyst, it should be pointed out that the further the cyclic flare height and approach speeds are from the nominal window (no corrective action) the greater and more demanding the corrective action required will be.

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1 It should be noted that the computer program is strictly a mechanical system (no visual feedback) and will only work within the input rates and limits imposed.

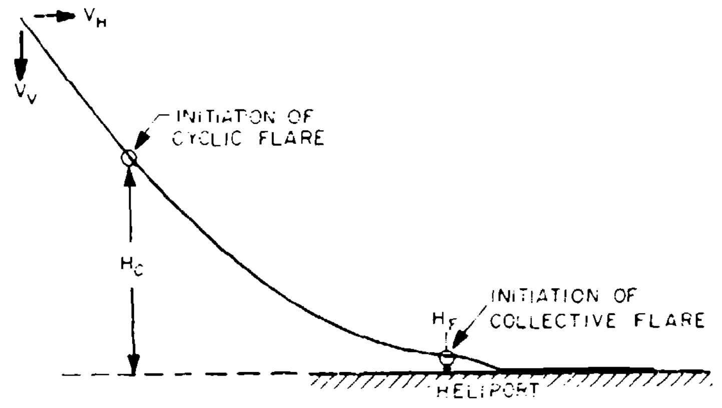


Figure 14. Typical autorotation flight path.

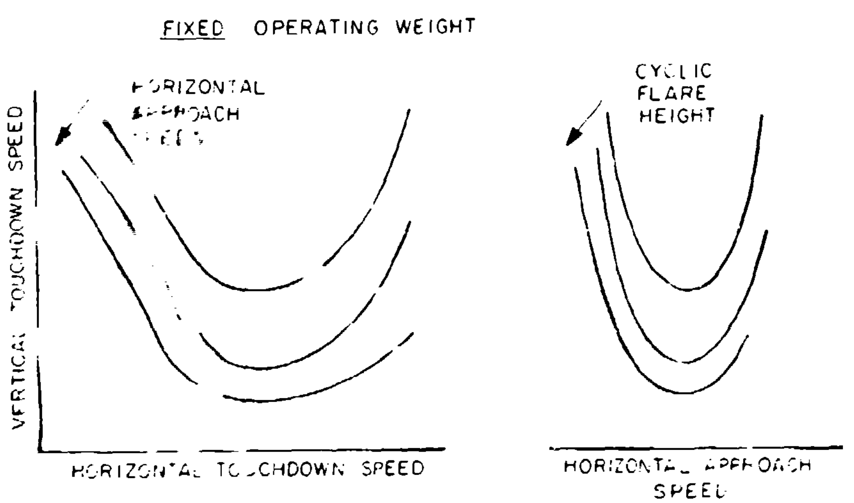


Figure 15. Typical autorotation trade-offs.

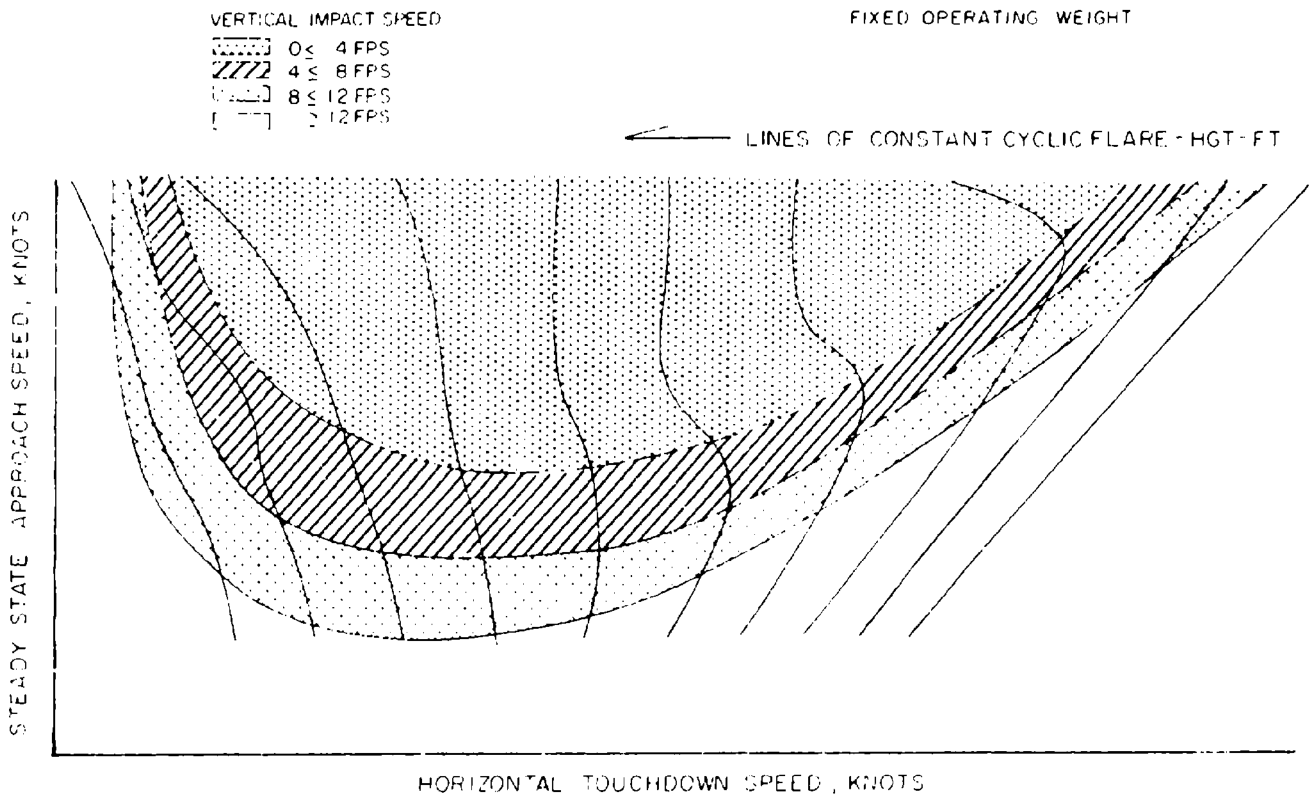


Figure 16. Typical cyclic flare gate envelope.

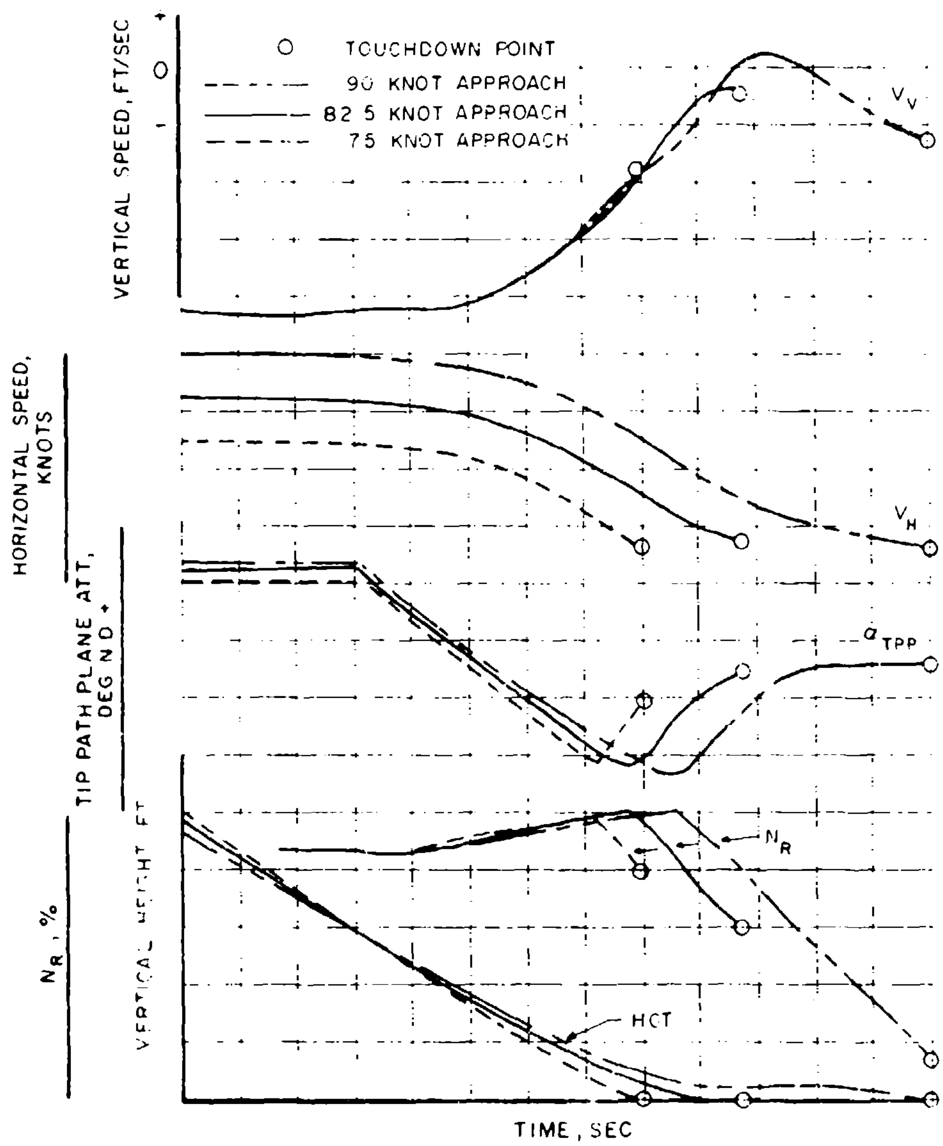


Figure 17. Typical autorotation time histories.

The previous discussion assumed that the rotorcraft had successfully entered autorotation and established a stabilized descent condition. This provided a means of determining the cyclic flare gate or basically, the minimum possible height from which a safe landing can be affected from a stabilized descent condition.

Analysis of the autorotative entry, transition from powered flight to stabilized autorotation, will establish the loss in height required to reach the stabilized descent condition. The minimum safe operating height will then be the sum of the entry height loss plus the cyclic flare gate height requirement.

The height loss associated with the entry is dependent on the flight condition at the time of total engine malfunction. The time delays used in recognition and reaction to the emergency are also a factor. Evaluation of these conditions should consider climbs, turns, level flight and dives under steady state and accelerating conditions to establish which entry condition yields the greater altitude loss. The effects of time delays, collective and cyclic must also be considered. The magnitude of these time delays affect rotor rpm excursions and possible pilot disorientation due to rapid airframe attitude changes. It should be noted that during autorotative entry negative G loadings are encountered. The pilot's ability to apply a consistent downward collective stick motion can be impared under these conditions. Although a flight condition might appear to be analytically safe, consideration must be given to the pilot's workload requirements under negative G loadings when establishing safe time delay criteria.

The procedures and trade-offs outlined in this section establish a generalized means of evaluating takeoff and landing capabilities. They, by no means, reflect the limiting trade-offs or required approaches to a given problem, but are only to be used as a guide. All of the trade-offs shown herein can be computed using the Helicopter Dynamic Performance Program. Since this program has been written in a generalized manner, the specific procedure in which a particular problem is approached is left to the ingenuity of the analyst.

3.6 BIBLIOGRAPHY OF REGULATORY REQUIREMENTS

TYPE CERTIFICATION STANDARD	Date of Issue
Civil Air Regulations Part 6 (CAR 6)	1946-1956
Civil Air Regulations Part 6 (CAR 6)	1956-1965
Civil Air Regulations Part 7 (CAR 7)	1956-1965
Special Conditions (for S-61)	1961
Interim Criteria	1961
Interim Criteria (Revised 1964, 1968)	1962
Interim Criteria	1963
Advisory Circular	1963
Federal Aviation Regulation Part 27 (FAR 27)	1965
Federal Aviation Regulation Part 29 (FAR 29)	1965
Federal Aviation Regulation Part XX (FAR XX)	1968

SCHEDULED AIR-CARRIER OPERATION STANDARDS

SR-353	1950
SR-369	1951
SR-400	1954
Civil Air Regulations Part 46 (CAR 46)	1958
Interim Criteria	1961
Interim Criteria	1962
Federal Aviation Regulation Part 127 (FAR 127)	1965

SEM-6506, March 1969, T. E. Dumont
"Explanation of FAA Transport Helicopter Categories A and B"

SER 611382, March 1968, T. E. Dumont
"A case for the Re-Evaluation of Airworthiness and Operations Criteria for Scheduled Air-Carrier Helicopter Operations from Elevated Heliports"

Military Specifications 7700A
Military Specifications MIL-H-8501A

4.0 CONSIDERATIONS FOR PROGRAM OUTPUT

The Helicopter Dynamic Performance Program was designed to work within user specified 'control input' rates and limits. While this allows the analyst unrestrictive use of 'control' input rates and limits reasonable judgement must be used in applying program input and output to 'real world' situations.

Say, for example, a horizontal takeoff procedure is to be analyzed. The user specifies in the input a delta horsepower of 500 and an initial wheel height of 5 feet. The program is not hindered by these inputs and determines that a 40° tip path plane angle is required to maintain the aircraft on a level flight path. Although the output appears to satisfy the distance requirements, for the study, the user must check to insure that sufficient blade tip clearance is available. Even if a 2-to-3 foot clearance is deemed sufficient, the analyst must ask,'is this clearance psychologically sufficient from the pilot's point of view to make this a viable solution?'

In the operation of the HDP program the user must always ask himself, 'Are the control input rates and limits structured so as to provide repeatability of the resulting flight path if an average pilot was to fly the maneuver?' Pilot work load requirements which can be disconcerting to the pilot are: control inputs which are abnormally slow; approach conditions to a specified point which are abnormally fast and require reverse control application to meet the requirements; and control motions required in a direction opposite the present G loading. Consideration must also be given to excessively rapid 'control input' requirements. Is it physically possible for the aircraft or aircraft systems to respond to the requested rate(s)? A rotor rpm change of 40% in 1 second is basically impossible, unless the rotor struck some object such as a tree etc. Items of this nature must be applied with reasonable judgement by the analyst prior to establishing the program output as a viable solution, representative of true aircraft capabilities.

The HDP program is also capable of analyzing a variety of auxiliary emergency devices. Use of these devices could provide the short duration energy required to improve the safety of flight for the emergency. Prior to stating that this is the device to use,let's take a look at these units as to their benefits and drawbacks.

Fly wheels. These units provide energy in the form of rotating inertia. They will provide energy to help minimize the rotor rpm loss after engine malfunction but the energy required to increase the rotor rpm during a cyclic flare is also increased. For a helicopter to autorotate, a free wheeling unit must be provided to disconnect the main rotor from the transmission. Once the main rotor is uncoupled by the free wheeling unit the fly wheel is also uncoupled unless it is attached to the main rotor shaft per se´. The location of the fly wheel in the drive train and its physical size dictates the energy available. Items that must be considered are the cost in horsepower to drive the fly wheel in nonemergency situations and the weight penalty required by the fly wheel and the containment structure necessary for safe operation.

Auxiliary power units. These units are generally classifed as short duration power units linked into the rotor system drive train. If these units rely on the aircraft system fuel supply consideration must be given to their usefulness if the reason for engine malfunction was due to running out of fuel. Another type of system is a solid propellent harnessed to a free turbine which in turn is geared into the drive train. Caution should be used when considering use of 'cast' solid propellents for helicopter operation. Normal helicopter operations generally subject the airframe to constant vibratory loads as well as impact loads during normal landings. These loads could cause cracking in the propellent. Depending on the manner of crack propagation these units could yield a pre-mature burn out or an explosive reignition. Adequate inspection procedures must be used to verify system integrity for practical application of these units.

Use of 'JATO' units requires the same concerns of propellent cracking as noted above. A further item which must be considered is the use of these units for landings. 'JATO' units produce [illegible] tip temperatures in the 2000-to-3000 degree range, depending on propellent type. The overall flame and heat boundaries can extend 100 feet below the nozzle. During landings the aircraft will be falling into this heated air mass. If the aircraft is in close proximity to the ground the reflected flame flash back could compromise the safety of the operation. Consideration must also be given to possible ignition of the landing surface be it asphalt or a cleared area type field.

If rotor tip rockets are being considered 'cast' propellent cracking must be considered. If a liquid propellent is being used provisions for preventing feeder tube flash back must be made to provide a viable operation. The use of tip rockets not only provides a short duration torque input benefit but also will provide an increased rotor inertia.

When emergency devices are used it must be assumed that they are carried on the aircraft at all times. The reliability of the system considered along with the weight penalty imposed by the particular system must be weighted against the benefits and/or safety of flight gain by their use. The computer program will always yield the same results for the same inputs. The user must ask, can a pilot repeatedly duplicate the flight path for the procedures developed? Is there sufficient margin for reasonable control variations and still maintain a safe operation? If the answers are yes, you have solved the problem.

5.0 DATA PLOTTING

The Helicopter Dynamic Performance Program has been set up with interactive plotting capability. Provisions have also been made to obtain 'Cal-Comp' plots for batch run processing.

A plot menu (selection) list containing 40 pertinent output parameters has been provided. This selection list is shown on page 68. It should be noted that any item on this list can be plotted against any other item on the list. Curve selection is always by index number. The input for plot selection always assumes the first index number to be the X axis and the second the Y axis. The input format is 2I2. Thus to obtain a plot of distance vs height the input would be 0302. Time vs rotor thrust would be 0114, etc.

Plot modes are selected by the input Location 220. Refer to Section 5.1 for interactive mode, Tektronix format, 5.2 for interactive mode Cal-Comp format and 5.3 for batch mode Cal-Comp format.

The program calculated height-velocity (H-V) curve, curve number 41, can only be plotted provided input location 231 has been set to ±1.X. An override is provided to allow the user to key in the four key H-V points (if known), i.e., low hover height, high hover height, horizontal speed and vertical height at 'nose' point.

This curve (41) cannot be plotted in conjunction with any of the other 40 curves.

AUTOROTATION MANEUVER CHARACTERISTICS
OF HELICOPTERS

PLOT MENU

INDEX		INDEX	
1	TIME	2	VERTICAL HEIGHT
3	HORIZONTAL DISTANCE	4	LATERAL DISTANCE
5	HORIZONTAL SPEED	6	VERTICAL SPEED
7	HORIZONTAL ACCEL.	8	VERTICAL ACCEL.
9	LONG.TPP. ATT.	10	LATERAL TPP.ATT.
11	ROTOR SPEED	12	SHAFT HORSEPOWER
13	TURN ANGLE	14	ROTOR THRUST
15	KINETIC ENERGY	16	POTENTIAL ENERGY
17	ROTOR ENERGY	18	PITCH ATTITUDE
19	ROLL ATTITUDE	20	THETA 75
21	FLIGHT PATH VELOCITY	22	FLT PATH KIN.ENERGY
23	FLIGHT PATH ANGLE	24	A/C ANG.OF ATTACK
25	ROTOR ANGLE OF ATTACK	26	ANG.ACCEL.LONG.AXIS
27	ANG.ACCEL.LAT.AXIS	28	VERTICAL FORCE
29	HORIZONTAL FORCE	30	LATERAL FORCE
31	PITCH RATE	32	ROLL RATE
33	ALPHA 75	34	INDUCED POWER
35	PROFILE POWER	36	PARASITE POWER
37	CLIMB POWER	38	TOTAL POWER
39	FLY WHEEL ENERGY	40	COMPOSITE POWER

41 H-V ENVELOPE

DO YOU WANT A 3-D VIEW OF FLIGHT PATH

5.1 INTERACTIVE MODE - TEKTRONIX FORMAT

To enter this mode of the graphics package, input location 220 must be set to (XX.1). XX refers to the print file output unit number.

After the completion of the flight path calculations, the user will be asked on the screen whether or not the plot menu is desired. An input of 1 will retrieve the menu, 0 will by-pass. An input value of 6 (integer) will return to main program for next case. When the menu display question appears, the plot package has been activated. Immediately after the menu, a question will appear which asks 'Do you want a 3-D view of the flight path?' The response to this is 1 if yes, 0 if not. These inputs are integer.

For the time being, let's assume the answer is no (0), the progam will ask for grid size, then solicit the index numbers for the variables you want to plot, i.e., IX IY. These inputs are also integer. Lets assume you have selected NO (0) for grids and 0302, horizontal distance vs vertical height, for the curve.

After this input, the program will solicit the baud rate for your operating system. This refers to the rate of line transmission between the computer and the terminal. If this rate is 30 bits per second, the input is 0300 120 bits/sec is 1200, etc. This input is only required for the first initialization of the plot package for the on-line session, i.e., it is only asked once per run.

The next solication will be 'Do you want to select scales?' Here again, 1 = yes, 0 = no. If you answer no (0), the scales will default to the data range and the plot will appear. If you answer yes (1), a message will appear stating the min-max of the data range, and you can then input the min-max values you desire. These inputs are one (1) per card in the order XMIN, XMAX, YMIN, YMAX. These values <u>must</u> have decimal points. The full scale range of the data <u>does not</u> have <u>to be</u> used, a 'blow up' of any portion can be selected. <u>The only</u> restriction is that all four values <u>must</u> be entered. The plot will appear after the 4th (YMAX) value is keyed <u>in</u>.

After the plot is finished, it will hold until the return key is hit. The program will then solicit with the question, 'Do you want a Cal-Comp copy?' This option was provided in this mode for convenience. See Section 5.2 for details if the response is 1 (yes). Here again, 1 = yes and 0 = no. If the answer is no (0), the program will return to the plot menu for further selections. Keying in a -1 at this point (i.e., when program asks for X-Y indices) will return to the main program for the next case data. (Clear the screen before keying in -1). To exit the program, key in a -1. number of blades (i.e., -1,1,-1.) then hit the return key. The user may now log off.

If the response to GRIDS is yes (1), the program will solicit for the grid density desired. This density refers to the number of grid lines to be superimposed on the plot. Valid inputs are 1 thru 9. In order to retain readable divisions it is recommended that the integers 1,2,4 or 5 be used.

If the user selects plot menu index 40, the curves output will be an overlay of the induced, profile, parasite, climb and total power. These curves are indexed for identification. The indicies are: I-Induced, O-Profile, P-Parasite, C-Climb, T-Total.

Let's go gack to the menu and answer the question 'Do you want a 3-D view of the flight path?' with a yes (1).

This response will solicit with the question, 'Do you want to change the view angle?' If the response is no (0) the 3-D view will be drawn from a predetermined viewing position. This view puts you in a position so as to belooking down on the flight path at a 20^{o} angle with the helicopter flying away at a 30^{o} angle for takeoffs and 30^{o} toward you for landings. It should be noted that for takeoffs the heliport is always square, for landings always rectangular. See Figure 18 on the following page for details on perspective viewing principles.

This view position can be changed by the user by answering yes (1) to the question. This input will then give you your present vantage point position and allow you to change any one or all of the items on the list.

The definition of these list items are:

1.	View Angle	The angle-measured from the horizontal at which the initial helicopter trajectory is leaving or approaching the heliport. Can be 0 to 360^{o} or $\pm 180^{o}$.
2.	Site Plane	The horizontal distance from the heliport at which you are standing. Must be a positive number.
3.	Elevation	The vertical distance from the heliport at which you are standing. Can be positive or negative.
4.	Picture Plane	The horizontal distance between the heliport and the plane that the image is projected on.
5.	Displacements	Generally not used for this adaptation. This input will displace the flight path from the ground plane by the number of feet input.

These inputs are keyed in I1, G20 format. To change the view angle from 30 to 125, the input would be 1 125, then hit the return key. You may now enter a second change to one or all of the other four view position items in the same manner.

After all the desired changes are made, hitting the return key the second time will initiate the plot.

The vertical lines are included to give the user a feel for the vertical displacement between the ground plane and the flight path. These lines nominally represent time steps of two seconds.

In any perspective viewing, the closer you are to the object the greater the distortion. As the viewer moves back toward infinity, the projection of the object (flight path in this case) onto the picture plane will go toward an ortho-graphic representation. If the picture plane is behind the viewer, the projection will reverse.

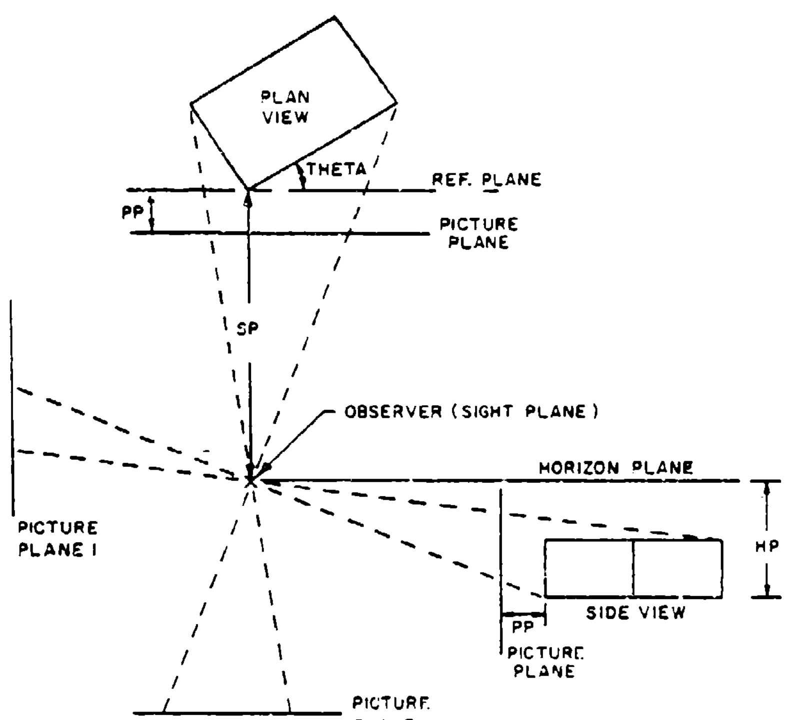


Figure 18. Perspective viewing principles.

5.2 INTERACTIVE MODE - CAL-COMP FORMAT

This graphics package mode is provided to permit the user to preview the curve in Cal-Comp format prior to writing the curve onto the output tape. The reason for this is the Cal-Comp plot routines are set up to scale the data ranges to integer inch lengths. Because of this, the scale range that is seen in Tektronix format is not necessarily the same scale range you will get in Cal-Comp format. Activating this package will show the exact Cal-Comp image and allow the user to change the scale range or the scale length on-line prior to curve acceptance. These controls are contained in what is referred to as the 'Z-Vector' control. A listing of the 'Z-Vector' control is provided in Section 5.2.1.

When input Location 220 is set to XX.1 or XX.2 the program is alerted to interactive mode and will ask questions as to your intent. If Location 220 was set to XX.1, refer to Section 5.1 for solicitations up to the question 'Do you want a Cal-Comp Copy?' This section applies assuming you answered yes (1). If Location 220 was XX.2 this question is implied and solicitation will not appear.

The next message to appear on the screen states that the Cal-Comp tape has been activated and the output unit number to which it is being written. No user response is required. The program will then ask 'Do you want to preview the plot?' If the response is 0 (No), the plot will go directly to the plot tape unit and return back to the menu list for your next selection. No curve will be seen in this mode. If the response is 1 (Yes), the 'Z-Vector' control is activated and the user has full control of the curve size and scaling. Transmitting the return key at this point will start plot action directly.

The next statement to appear is 'key in a 'P' to preview plot.' If the letter 'P' is not transmitted all curves will go directly to the plot tape unit. The next statement is 'key in 'A' to accept, 'E' to erase'. What you see on the screen is what you're accepting. <u>If the screen is blank always accept it</u>. This is the spacing between the plots on the output tape. After accepting the spacing the curve will appear. If the curve is acceptable key in an 'A'. This will put the curve on the plot tape. If it is not acceptable key in a 'E', erase this curve and return to the 'Z-Vector' control.

If the curve was accepted, transmitting a -6 will return you to the plot menu.

If it was not acceptable, select the 'Z-Vector' control(s) to change, change them and re-preview the curve until it is acceptable.

A yes (1) answer to 'equalize frame' will minimize the distortion on the plot prevue.

5.2.1 'Z-Vector' Control

The plot package provided contains a data string which controls the plot. The inputs are keyed in I2, G20.4 format. The available options, input location and numerical input value to use are shown on page 74. The options for plot type, orientation and resolution are self-explanatory. The interfacing between scale length and user supplied scale ranges should be fully understood prior to using them.

The input for axis length refers to the maximum scale length in inches the user will accept. It can be no greater than 16 inches, or less than 2 inches. If the user selects the scale range, Locations 8-10 or 11-13, the axis length must be such that the equation

$$LOC\ (3) = (LOC\ (9) - LOC\ (8))/LOC\ (10)$$

is satisfied with integer numbers and LOC (10) must be a multiple of 1, 2, or 4. This also applies to the Y axis selection. Since the data range of the various curves on the menu list has wide variations a fixed setting for all curves becomes impractical and the default values were used. To minimize user problems in scale selection the following procedures is recommended.

Set Location(s) 3 and/or 4 to the maximum length you will except. One of these scales must be 9 inches or less. Set Location(s) 6 and/or 7 to 1. Load Locations 8 - 10/or 11 - 13. The program will adjust the scale length to provide the best logical scaling.

If Location(s) 3 and/or 4 are input as 0, the scale length will be determined internally using the appropriate equation Location (3) or Location (4).

When plotting curve number 40, the following symbols are used:

○ - Induced Power

□ - Profile Power

▷ - Parasite Power

◁ - Climb Power

◇ - Total Rotor Power

NOTE: The user cannot manipulate the 'Z-Vector' controls in batch mode operation.

Z VECTOR CONTROLS
CAL-COMP PLOT PACKAGE

OPTION	LOC	VALUE	DESCRIPTION
Plot Type	1	0.0	Regular Plot - Lines & Symbols
		2.0	Scatter Plot - Symbols Only
		3.0	Regular Plot - Symbols 1" Apart
		4.0	*Line Plot
Orientation	2	1	Y-Axis Across Paper
		2	*X-Axis Across Paper
		3	Y-Axis Across Paper - No Axes Drawn
		4	X-Axis Across Paper - No Axes Drawn
			A Negative Value Will Produce A Grid of 1 Inch Squares
X-Axis	3	Length	Max. Length in Inches Integer (Default = 6)
Y-Axis	4	Length	Max. Lenth in Inches Integer (Default = 8)
Resolution	5	0.0	*No Equal Resolution
		1.0	Equal Resolution Based on X-Axis Scales
		2.0	Equal Resolution Based on Y-Axis Scales
Scaling	6	0	*Automatic Scaling X-Axis
		1	User Supplied Scaling X-Axis. See LOC 8,9,10
Scaling	7	0	*Automatic Scaling Y-Axis
		1	User supplied Scaling Y-Axis. See LOC 11, 12, 13
User X-Axis Scales	8	X-First	Defaults to Automatic Scaling if Not Input.
	9	X-Last	
	10	DX	
			For User Input the Equations:
User Y-Axis Scales	11	Y-First	LOC(3)=(LOC(9)-LOC(8))/LOC(10) and
	12	Y-Last	LOC(4)=LOC(12)-LOC(11)/LOC(13) must be
	13	DY	satisfied with integer numbers, and multiples of 1, 2 or 4 $*10^N$

*Default values

5.3 BATCH PROCESSING - CAL-COMP FORMAT

When operating HDP in batch mode the Cal-Comp plot package can be activated by loading input Location 220 with XX.3, where XX is the output file number. This location must not be loaded as XX.1 or XX.2, run termination will result.

Operating in this mode will provide the same plot menu selections as interactive mode although the user must anticipate the questions and respond with card inputs.

The list of questions and the order in which they appear are listed in this section. Strict adherence to this list must be followed to maintain run stream continuity.

The first input request will be; 'Do you want a perspective view?' Thus a card input with a 0 or a 1 in column one is required. CAUTION: The first plot of a batch run must not be a perspective view. If the answer is no, (0), the next card input must contain the X,Y index values to be plotted. See page 68 for index list.

The requested curve will be sent directly to the plot tape and the program will return to the query for perspective view.

If a perspective view is desired, a 1 punch in column one of the next card, the program wants to know if you want to change the view angle. A 0 punch is no, a 1 punch is yes. If the answer is no (0), the perspective view will be set up with default values and sent directly to the output tape. If a 1 punch is used the following items can be changed:

1 View Angle	3 Elevation	5 Displacement
2 Site Plane	4 Picture Plane	

If the view angle is to be changed to 45° the input card would be 1 45. The 1 is in column one. The 45. can be anywhere within the next 20 card columns. This value must contain a decimal point. After all desired values are changed, insertion of a blank card will generate the plot and the program will return to the statement 'Do you want a perspective view?' Insertion of another blank card followed by a card with -1 in columns 1 and 2 will release the plot package and return to the main program for the next case.

A sample plot run stream is shown below for reference.

EXAMPLE: Obtain Cal-Comp plots in batch mode.

Plots desired are, height vs distance
horizontal speed vs distance
vertical speed vs distance
composite power vs time
perspective view at default values
perspective view at -60°.

In base loader data set Location 220 = XX.3, assuming unit 10 is being used for the output file then the last card of the loader case data would be

```
Column

1  2  3  4  5  6  7  8  9  10

-  1     2  2  0     1  0  .3        . Last loader card
0                                    . No 3-D plot
0  3  0  2                           . First curve
0                                    . No 3-D plot
0  3  0  5                           . Second curve
0                                    . No 3-D plot
0  3  0  6                           . Third curve
0                                    . No 3-D plot
0  1  4  0                           . Fourth curve
1                                    . 3-D plot
0                                    . Default values
1                                    . 3-D plot
1                                    . Change view angle
1  -  6  0  .                        . View angle changed to 60°
 Blank Card                          . Plot it
 Blank Card                          . Set for return
-  1                                 . Return
```

Ready for next case.

6.0 OPTIMIZING OPERATIONAL CAPABILITIES

Optimization can be loosely defined as a solution looking for a problem. The problem generally arises when trying to define what is optimum. Take the case of defining the optimum flight path for a takeoff or landing maneuver. The first question asked is, 'Optimum to what?' To the Aerodynamacist it would be the resulting flight path which maximizes the aerodynamic capabilities of the aircraft. The structural engineer is concerned in minimizing the aerodynamic and touchdown impact loads for the optimum path. The accoustic engineers say the optimum flight path is that which minimizes the accoustic footprint. Passengers want the flight path which maximizes passenger comfort. Pilots indicate the optimum to be that path which can be repeatably attained without any abnormal work loads.

The criteria listed above are the primary considerations which must be used for establishing the optimum. Other parameters such as field size, field location (ground level or elevated), field surface type, and aircraft geometric constraints must also be considered.

The analyst, when asked to establish the optimum flight path, finds himself in a quandary due to the number of variables which must be considered. To avoid this situation the analyst must first ask, 'For what constraints do you want the optimum?' These constraints must be established before any logical analysis can be conducted. With the basic constraints and/or considerations defined the HDP Program can be used to evaluate various flight paths using orderly parametric variations. Section 3 of this report provides a guide as to a basic procedure or approach to use for typical flight path analysis. The 'optimum' flight path and flight procedures required to attain that path will be that path which pushes to the limit but does not violate any of the imposed constraints.

6.1 OPTIMIZING THE HEIGHT-VELOCITY ENVELOPE

The HDP Program has four optimization routines associated with it. Three of these pertain to establishing the height-velocity (H-V) envelope. An H-V envelope can be defined as, that combination of height and velocity from which a safe landing can be effected in the event a total or partial power loss is experienced. Operation within the boundaries of this curve could result in hard or catastrophic landings. A typical H-V envelope is shown in Figure 19.

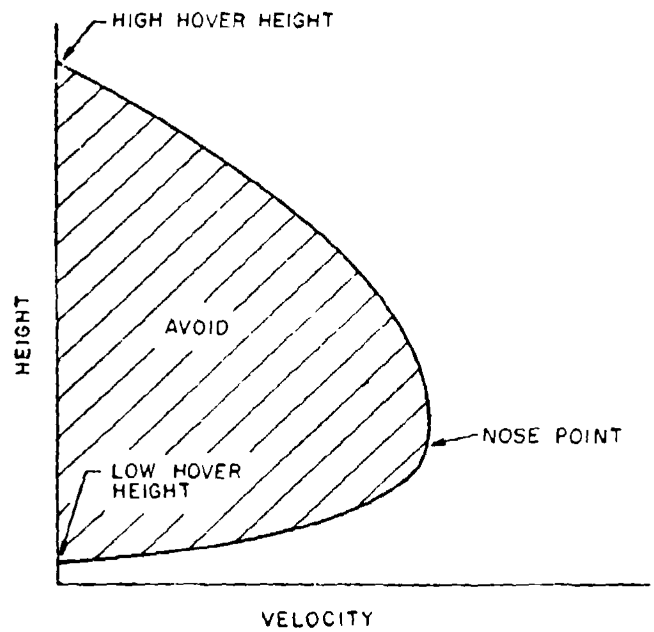


Figure 19. Typical H-V envelope.

As previously mentioned, a large number of constraining variables come into play. The various considerations used in the development of these routines will be discussed so that the user will have a better understanding of the resulting output and the input controls available.

6.1.1 H-V Low Hover Height

This point on the H-V curve can be defined as the maximum height from which a pure vertical descent can be made after total or partial power loss. The program constraints for evaluating this point is to adjust the collective as necessary to attain a specified vertical touchdown velocity without exceeding the rotor system CT/σ limit. The user can control these items by program input. The CT/σ limit is input in location 35 and the desired vertical touchdown speed can be specified in location 232. Rotor N_R limits and Theta 75 limits can be specified in locations 236 and 238. If the collective stick Theta 75 must be momentarily decreased to attain the desired touchdown speed, the rate of collective dump can be varied by specifying in input location 253. It should be pointed out that rapid collective dumps result in high negative G loadings. The ability of the pilot to continuosly apply a downward force in this environment could be impared. The program will assume a full dump in 1 second if the user does not specify a rate.

With these controls the maximum low hover height from a structural standpoint can be obtained by specifying the vertical velocity and CT/σ limit at their structural limit values. Variations for pilot workload capabilities and consistantly repeating the conditions can be attained by variations in either or both of these variables.

This portion of the optimizer is turned on when input location 231 is set to 1.1. This input will evaluate the low hover height only.

When program operation is conducted in the optimization mode, input location 231 set to 1.x, increased computer running time will result. This is due to the program generating the control inputs required to 'optimize' to the imposed conditions. In view of this it is recommended the 'Batch' processing be used. This is accomplished by setting input location 220 to XX.0. The program will provide a listing of the inputs and locations required to attain this 'optimum' condition. The user can then set up an interactive run with these inputs if detailed plots are desired. A listing of the inputs which the user <u>must</u> provide is given in section 6.3 of this report.

6.1.2 H-V Nose Point

The nose point of an H-V diagram can be defined as the vertical height at which the maximum horizontal velocity is required tc affect a safe landing should a total or partial power loss occur.

In the optimization of the H-V nose point the vertical touchdown velocity and C_T/σ limits are used as the primary constraints. Secondary constraints of horizontal touchdown velocity and airframe attitude at touchdown are also applied. These secondary constraints have their weighted importance factors controllable by the user through input ranges that will be acceptable. Thus if the horizontal touchdown speed is not critical to the conditions the user could specify a minimum of 0 knots and a maximum of 20 knots.

The program will search for the 'optimum' flight path which meets the vertical touchdown speed and C_T/σ limits with the constraint that the horizontal touchdown speed be within the range specified. In this manner the importance of the horizontal touchdown speed can be controlled by "squeezing" in the acceptable range. The relative importance of the touchdown body attitude can be controlled in the same manner.

This portion of the optimization routine is turned on when input location 231 is set to 1.2. This input will evaluate the H-V nose point only. The same provisions for batch and inter-active program operation as apply to the low hover height section 6.1.1 are applicable for this evaluation. A listing of the inputs which the user <u>must</u> provide is given in section 6.3 of this report.

6.1.3 H-V High Hover Point

The high hover point of the H-V diagram can be defined as the minimum altitude, above the nose point, from which a safe landing can be effected after total or partial power loss. Acceleration to some forward speed is generally required to conduct this maneuver. If a pure vertical landing path could be attained from this point, it would demonstrate the absence of a H-V envelope for the operating weight and ambient conditions imposed. The program constraints used here are the same as employed in evaluating the H-V nose point. Two additional inputs are required over and above the list shown in section 6.3. These pertain to the maximum tip path plane attitude used during the acceleration from the hover and the time to reach this tip path plane attitude. These inputs are input in locations 123 for TPP attitude and 133 for the time input. The program will work within the tip path plane limit imposed but not necessarily use it. This evaluation can be conducted by setting input location 231 to 1.3. The same provisions for batch and inter-active program as apply to the low hover height are applicable for this evaluation.

It should be noted that all three H-V critical points can be evaluated in one setup if input location 231 is set to 1.0. It is recommended that this run be set up as a batch run if this switch setting is used. Interactive runs can be made using the input lists provided on the batch run output.

6.2 MAXIMUM RANGE IN AUTOROTATION

The HDP program has an option routine associated with it which establishes the horizontal speed at which the maximum horizontal distance can be attained. The resulting output from the program relates the horizontal velocity required and the associated horizontal distance covered per 1,000 feet of altitude. The distance covered from the point of engine malfunction to the maximum glide slope speed and the distance required to effect a full autorotative landing from the maximum glide slope speed are not considered in this evaluation.

This option can be accessed by setting input location 231 to 1.4. The minimum input requirements for this evaluation are shown in section 6.3. Note that input locations 45-133 and 232-253 are not required for this mode.

Program operation will not be effected if these inputs are loaded. As in the other optimization modes the inputs required to duplicate the 'optimized' run will be listed along with the program output.

6.3 INPUTS REQUIRED FOR H-V OPTIMIZING

The optimization routines provided in the HDP program internally generates the control inputs required to attain a solution. This internal generation of input data does not affect the base case data as loaded. The original data as loaded into the program will still be there after the optimized run is completed. Thus any base case data can be used and the optimizer used in conjunction with it.

The following list provides the user with the loader input locations which must be loaded for successful operation of the optimizer.

Input Location	Definition	Default Values
1-23	Aircraft Configuration Data	0.0
25	Pressure Altitude	0.0
26	Ambient Temperature	0.0
27	Operating Weight	0.0
33	Heliport Elevation	0.0
35	C_T/σ Limit	0.15
38	Initial Rotor Tip Speed	100.0 %
41-44	A/C Heading and Wind Conditions	0.0
45	Collective Time Delay	1.0 Sec
46	Longitudinal Cyclic Delay	0.0
47	Lateral Cyclic Delay	0.0
48	Autorotation Recovery RPM	100.0 %
124*	Maximum Tip Path Plane Attitude	20 Deg
134*	Time to Max. Tip Path Plane Attitude	2 Sec
151-190	Lateral Maneuver Control Inputs	0.0
191-200	System Mechanical Efficiency	100. %
201	Fixed Power Losses	0.0
202-206	Must be Set to 0.0 for Optimized Runs	0.0
207-218	Any of these Options can be used in the Optimization Mode.	0.0
219	Primary Output File	6.0
220	Secondary Output File	10.0
221-224	User δ-C_{LM} Coefficients	0012 Airfoil

Input Location	Definition	Default Values
231	Optimizer Switch	0.0
232	Allowable Vertical Touchdown Velocity	3.0
233	Remaining Power After OEI	0.0
234	Min. Max Horizontal Touchdown Speed	0-15 Kt
235	Min. Max. Body Attitude at Touchdown	0-12 Deg
236	Max. Min. N_R Allowed	120-50%
238	Min. Max. Theta 75 Limits	0-18 Deg
253	Maximum Time of Collective Dump (If Necessary)	1 Sec
261	Maximum Flare Angle used for H-V Nose Point Evaluation (must be negative)	-20 Deg
298-299	Pitch Roll Dampers	0.5

*Used in high hover height evaluation only.

Input locations 45-133 and 232-253 not required for maximum autorotation range calculations.

The default values as shown are the values which will be used if the user does not load them. If an input location is not shown on this list,it need not be loaded.

The program will provide a listing of the input values required to generate the 'Optimized' case. Input location 231 should be set to 0.0 when using this data in an inter-active mode.

7.0 PROGRAM ORGANIZATIONAL CHART

The Helicopter Dynamic Performance (HDP) Program was developed with a modular concept. This concept allows for particular subroutine groupings to be called from several other subroutines. This in turn permits the flexibility to analyze various flight modes within one program.

Due to their size and number, the subroutine organization charts for the HDP Program are contained in a separate compendium. Copies of these charts may be obtained upon written request to the Applied Technology Laboratory, Aeromechanics Technical Area, Fort Eustis, Va. 23604, or by contacting Mr. G. T. White, Aeromechanics Technical Area, phone (804) 878-3874/2062 or Autovon 927-3874/2062.

8.0 PROGRAM OUTPUT

The Helicopter Dynamics Performance Program printed output provides a basic flight summary and a detailed time history output.

The flight summary section provides a listing of the basic aircraft geometry, atmospheric conditions and operating weight for the case analyzed. The flight is then summarized as to the conditions which existed at the start of each event and the conditions at the end of the flight. Output diagnostics and/or pertinent information for special conditions which occurred during the flight are also listed with the summary. The summary page also notes the output distance reference point for landings. For power on landings all distances are referenced to the edge of the heliport. Autorotations reference the distance to the cyclic flare point. All other flight modes are referenced to the initial point and are not noted on the summary sheet.

For landings and rejected takeoffs the vertical touchdown velocity is noted. Takeoffs and balk landings print out the horizontal and lateral distance required to reach a specified wheel height. This height is assumed to be 50 ft unless otherwise specified in input Location 24.

A breakdown of the values listed in the flight summary and the reference system used are as follows.

Time (seconds)	Measured from start of flight.
Height (ft)	Measured vertically from heliport surface to a/c wheel or skid landing gear.
Distance horizontal (ft)	Measured from start of flight unless otherwise noted. Ground distance.
Distance lateral (ft)	Measured from start of flight.
Velocity (knots)	Horizontal air speed (earth axis system)
Velocity (fpm) Vertical	Vertical air speed (earth axis system)
ANR (percent)	Rotor RPM measured in % of a/c design tip speed.
TPP Att. Long. (deg)	Longitudinal tip path plane angle measured in degrees. In earth axis system. A positive angle will accelerate the a/c.
TPP Att Lateral (deg)	Lateral tip path plane angle measured in earth axis system. A positive angle will cause a right turn.
SHP	Total shaft horsepower developed by the a/c main engine(s).

M. R. Thrust (lb)	Total rotor thrust in pounds measured normal to the tip path plane angle.

The output is also available as a detailed time history. This output is provided in 1/2 second time intervals for the total flight. This section of printed output is optional and can be suppressed by setting input Location 220 as a negative number. Suppressing this output will not affect graphical output. All values listed in the detailed time history have the same reference basis as listed for the summary sheet. The values available over and above these are listed below.

ACC(G's)	Horizontal or vertical acceleration measured from 1 G (steady state flight). The accelerations listed are the average acceleration across the time interval.
Pitch (deg)	Airframe pitch attitude in degrees. Earth axis system.
Roll (deg)	Airframe roll attitude in degrees. Earth axis system.
Theta 75 (deg)	Collective pitch setting @ .75 Rc. Mean average value.
KE (hp-sec)	A/C kinetic energy. Measured in horizontal plane.
PE (hp-sec)	A/C potential energy. Measured in vertical plane. Computer from the main wheels or skids and referenced to the heliport surface height.
RE (hp-sec)	Rotor energy. Rotational energy of rotor system.
Turn Angle (deg)	Angular displacement of flight path from initial heading. Increasing values indicate a right turn.
M.R. Thrust (lb)	The thrust values listed in the detailed time history are the average thrust values across the time interval. It is measured normal to the tip path plane.

The next section of the output provides a more detailed breakdown of the time history. This section of the output can be suppressed by setting input Location 219 to a negative value. The suppression of this output does not affect the ability of obtaining graphical output of these values. The output items listed are:

Time (seconds)	Measured from start of flight.
Total SHP	This is the total shaft horsepower at the main rotor(s) delivered by the primary a/c engine(s).

The power absorbed by the main rotor is broken down into four basic components. These are listed as:

Induced (hp)	The power required to overcome the induced drag.
Profile (hp)	The power required to overcome the profile drag of the blade.
Parasite (hp)	The power required to overcome the drag of the basic airframe.
Climb (hp)	The power required or absorbed (-) in changing the a/c elevation.
Flywheel KE (hp-sec)	If a flywheel is used the energy level of the flywheel, in hp-sec, is listed.
Flight Path KE (hp-sec)	The a/c kinetic energy level along the flight path axis is listed. It is in the units of hp-sec.

The airframe angular accelerations in pitch and roll are listed in degrees per second per second.

Flight Path Velocity (kn)	The resultant velocity of the a/c along the flight path is provided in knots.
Flight Path Angle (deg)	The a/c flight path angle, measured relative to the ground is listed in degrees.
A/C Angle of Attack (deg)	This output is referenced to the wind axis system and is output in degrees.
Rotor Angle of Attack (deg)	This output is also referenced to the wind axis system and is output in degrees.
Alpha 75 (deg)	Mean average blade angle of attack in degrees.
Rotor Forces (lb)	The resultant rotor forces, measured in the earth axis system are listed in pounds.

Airframe Angular Rates (deg/sec)	The angular rates of airframe rotation about the longitudinal, and lateral axis are listed in degrees per second.

A sample output listing is provided on the following page for reference. This listing is shown for reference only and does not constitute a flight path of significant meaning.

TYPICAL LOADER INPUT

5	1	2.	.15	2.25	22.	2670.
5	6	-10.	33.95	0.	26.72	-2.375
5	11	0.	.1	14.5	.0275	11.58
5	16	0.816	2265.	11800.	9900.	0.0
5	21	0.	0.	0.	60.	C.
5	26	15.	9800.	95.	64.	0.
5	31	0.	30.	0.	1.	.15
5	36	.5	5000.	100.	0.	0.
5	41	0.	0.	0.	0.	1.
5	46	1.	0.	100.	5.	1.
5	51	0.	1.	1.	1.	0.
5	61	1.	80.	20.	0.	4.
5	71	64.	0.	0.	0.	-.5
5	81	1000.	0.	0.	0.	0.
5	91	100000.	.5	1.	1.	1.
5	101	100.	100.	110.	70.	100.
5	111	1.	1.	5.	4.	6.
5	121	2.	-20.	-20.	-8.	-10.
5	131	1.	4.	4.	2.	2.
5	141	.6	.6	.6	.6	.6
5	151	0.	0.	0.	0.	0.
5	161	1.	1.	1	1.	1.
5	171	0.	0.	0.	0.	0.
5	181	.6	.6	.6	.6	.6
2	191	0.88	50.88			
1	201	30.				
5	251	1.	1.	1.	1.	1.
2	298	.0011	.0011			
2	219	10.0	11.1			
4	221	0.014133	-0.011078	.004192	.00842	
5	231	0.	-5.	0.	.15	.8
1	236	120.5				
1	238	0.18				

1

IBM TEST

OPERATING WGT.	=	9800.0 LBS.	NO. OF BLADES	=	2.	
PRESSURE ALT.	=	0.0 FT.	BLADE CHORD	=	2.25	FT.
AMBIENT TEMP.	=	15.0 C.	BLADE RADIUS	=	22.0	FT.
WIND VELOCITY	=	0.0 KTS.	BLADE TWIST	=	-10.0	DEG.
WIND DIR. HORIZ	=	0.0 DEG.	DISC SOLIDITY	=	0.0650	
WIND DIR. VERT.	=	0.0 DEG.	AIRFRAME F	=	14.5	FT**2
			DISC AREA PROJ	=	1520.5	FT**2
CASE NUMBER	=	1.	AREA RATIO	=	1.000	

FLIGHT SUMMARY

TIME (SEC)	HGT (FT)	DIST (HORIZ)	DIST (LAT)	VEL (KTS) LONG	VEL FPM VERT	ANR PERCENT	TPP ATT LONG DEG	TPP ATT LAT DEG	SHP	M.R.THRUST (LBS)
				START OF EVENT 1						
0.0	95.0	-573.4	0.0	64.0	0.0	100.0	1.2	0.0	594.4	9829.9
				START OF EVENT 2						
1.000	55.0	-465.2	0.0	64.0	0.9	100.0	1.2	0.0	594.4	9833.9
				START OF EVENT 3						
4.281	80.0	-116.6	0.0	58.9	-513.8	90.1	-13.6	0.0	0.0	8877.3
				START OF EVENT 4						
7.356	20.0	153.4	0.0	43.0	-1382.4	106.4	-19.3	0.0	0.0	9851.0
				START OF EVENT 5						
9.356	0.0	273.0	0.0	30.7	-0.0	87.1	-8.3	0.0	0.0	10674.6
				CONDITIONS AT END OF FLIGHT						
12.356	0.0	396.6	0.0	16.0	-0.0	94.9	-10.0	0.0	0.0	7364.0

DISTANCES ARE REFERENCED TO CYCLIC FLARE POINT

VERTICAL TOUCHDOWN VELOCITY WAS -8.7 FT/SEC

CT/SIGMA LIMIT EXCEEDED DURING FLIGHT ** CHECK ROTOR BLADES **

1

DETAILED TIME HISTORY OUTPUT
** ESTIMATED **

TIME (SEC)	HGT. (FT)	DIST. (HORIZ)	DIST. (LAT)	VEL. (KTS) (LONGITUDINAL)	ACC G'S (LONGITUDINAL)	VEL (FPM) (VERTICAL)	ACC G'S (VERTICAL)	PITCH DEG	ROLL DEG (AIRFRAME)	THETA 75 DEG
0.0	95.0	-573.4	0.0	64.0	0.000	0.0	1.001	-1.2	1.1	10.6
0.50	95.0	-519.3	0.0	64.0	0.000	0.5	1.000	-1.2	1.1	10.6
1.00	95.0	-465.2	0.0	64.0	-0.000	0.9	0.981	-1.2	1.1	10.6
1.50	94.9	-411.1	0.0	64.0	-0.002	-17.0	0.921	-1.2	1.1	10.7
2.00	94.5	-357.0	0.0	64.0	-0.016	-93.7	0.816	-1.2	1.1	10.1
2.50	93.0	-303.0	0.0	63.8	-0.058	-271.0	0.850	-0.7	1.1	11.6

DETAILED TIME HISTORY OUTPUT
** ESTIMATED **

TIME (SEC)	ANR PERCENT	TPP ATT (LONG) (DEG)	TPP ATT (LAT) (DEG)	SHP	KE HP-SEC.	PE HP-SEC.	RE HP-SEC.	TURN ANG (DEG)	M.R. THRUST LBS.
0.0	100.0	1.17	0.0	594.4	3236.	1693.	2798.	0.0	9834.9
0.50	100.0	1.18	0.0	594.4	3236.	1693.	2798.	0.0	9833.9
1.00	100.0	1.18	0.0	594.4	3237.	1693.	2745.	0.0	9646.9
1.50	98.1	1.18	0.0	0.0	3236.	1692.	2573.	0.0	9043.5
2.00	93.7	1.18	0.0	0.0	3235.	1683.	2395.	0.0	8007.2
2.50	[illegible]	-0.49	0.0	0.0	3220.	1656.	2295.	0.0	8341.2

DETAILED TIME HISTORY OUTPUT
** ESTIMATED **

TIME SEC.	TOTAL RHP	INDUCED (HORSEPOWER)	PROFILE (HORSEPOWER)	PARASITE (HORSEPOWER)	CLIMB (HORSEPOWER)	FLY WHEEL (HP-SEC)	FLT.PATH KE (HP-SEC)	ANGULAR ACCELERATIONS (DEG/SEC**2) PITCH	ROLL
0.0	496.6	227.9	229.0	39.6	0.1	0.0	3236.5	0.0	0.0
0.50	496.7	227.8	229.0	39.6	0.2	0.0	3236.5	-0.0	0.0
1.00	496.7	219.4	221.8	39.5	-2.4	0.0	3236.6	-0.0	0.0
1.50	0.0	193.1	199.4	39.5	-16.4	0.0	3236.3	-0.0	0.0
2.00	0.0	152.8	174.7	39.4	-83.2	0.0	3235.4	1.8	0.0
2.50	0.0	168.0	167.1	38.8	-115.1	0.0	3225.4	6.3	0.0

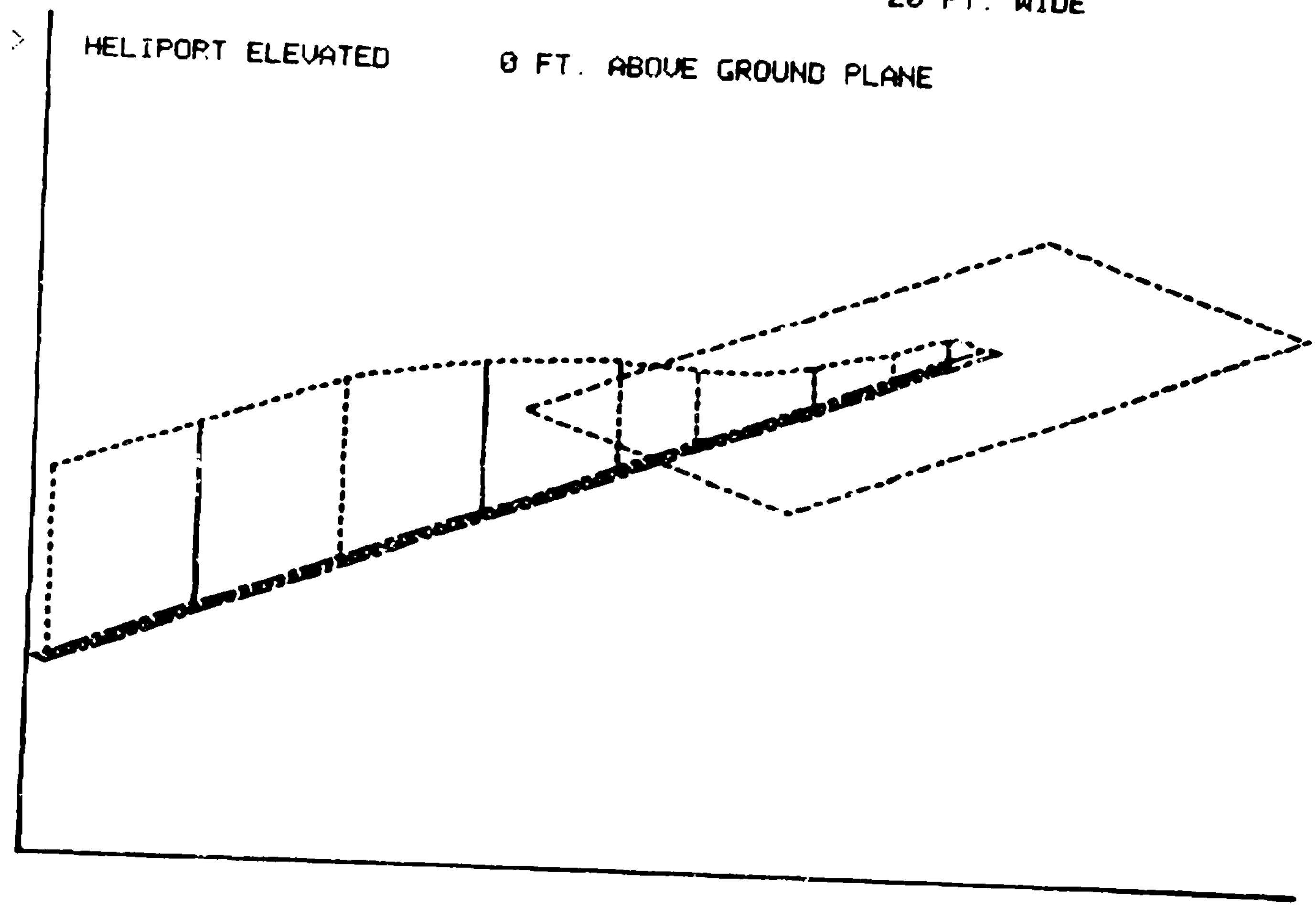
DETAILED TIME HISTORY OUTPUT
** ESTIMATED **

TIME SEC.	FLT.PATH VELOCITY KNOTS	FLT.PATH ANGLE DEG	A/C ANGLE OF ATTACK DEG.	ROTOR ANGLE OF ATTACK DEG.	BLADE ANGLE " .75 R DEG.	ROTOR FORCES VERTICAL LBS	ROTOR FORCES HORIZONTAL LBS	ROTOR FORCES LATERAL LBS	AIRFRAME ANGULAR RATES LAT.AXIS DEG/SEC.	AIRFRAME ANGULAR RATES LONG.AXIS DEG/SEC.
0.0	64.0	0.0	-1.2	1.2	9.4	9832.9	201.5	0.0	0.0	0.0
0.50	64.0	0.0	-1.2	1.2	9.4	9831.8	201.8	0.0	-0.0	0.0
1.00	64.0	0.0	-1.2	1.1	9.4	9644.9	198.0	0.0	-0.0	0.0
1.50	64.0	-0.1	-1.0	0.7	9.6	9041.6	185.6	0.0	-0.0	0.0
2.00	64.0	-0.8	-0.3	-2.1	9.6	8007.1	48.2	0.0	0.9	0.0
2.50	63.9	-2.4	1.7	-6.0	10.8	8333.1	-368.0	0.0	3.2	0.0

CASE 3.

FIELD OF VIEW 1472 FT. LONG
20 FT. WIDE

HELIPORT ELEVATED 0 FT. ABOVE GROUND PLANE



9.0 PROGRAM VERSIONS

The Helicopter Dynamic Performance Program was developed on a UNIVAC 1110 computer system, version 32122A/21. It was written in Fortran IV for operation on an IBM 360 and a CDC 6600 computer. In the development of the program, as many routines as practical were written on a computer independence basis for transportability. Of the 121 subroutines required, exclusive of the Tektronix plot package, eighteen subroutines are computer dependent. One of these subroutines also requires modification dependent on the Tektronix plot 10 and AG II release level, be it release 3.1 or 3.3. The affected routines and card line number changes required are listed below. The code is such that a switch in comment cards is all that is required.

Subroutine Name	Reason	Use Line Number	
		IBM	CDC
Y239TL	Wo:d Size	39, 62, 63	43, 67, 68
HVA	ARCOS, ACOS	92	88
CLECT	Word Size	18	22
OUTPT	Word Size	21, 52, 225,	25, 56, 229
SEEDAT	Data Statements	13, 14	18, 19
INPRNT	Data Statements	14, 15	19, 20
BDYAT	ARSIN, ASIN	47, 60	43, 56
PLOTA	Word Size TCS 10 Release	39 57 Release 3.1 58 Release 3.3	43 57 Release 3.1 58 Release 3.3
LABL	Word Size	Use as is.	New routine req'd.
PERPLT	Word Size	21, 41-44, 289-291, 308-310	25, 48-51, 295-297 314-317
HVPLT	Word Size	12, 54	14, 49
LABELS	Word Size	38, 39	46, 47
TYPE	ARCOS, ACOS	24	28

Subroutine Name	Reason	Use Line Number	
		IBM	CDC
ALABEL	Word Size	18	21
MVCHAR	Word Size	Use subroutine MVCHAR	Use subroutines: GETCHAR PUTCHAR
TUBPLT	Entry Points	Use as is	Remove argument list
EQRES	Entry Points	Use as is	58
DATSCL	Entry Points	Use as is	6, 41

The program as delivered has been set for the IBM 360/65 computer, using the Tektronix Plot 10 release level 3.3 and graphical output for the GT-40 inter-active tube. Hard copy plots are assumed to be for a Houston plot bed.

The 360/65 version must be compiled using the IBM G1 Fortran Compiler with the compatable system libraries for successful operation of this program.

9.1 PROGRAM OPERATION

The Job Control Language (JCL) for various computer installations vary so no detailed explanation of the JCL required for program access is possible.

The basic requirements in setting up the JCL for the Helicopter Dynamics Performance Program is the print and plot unit file assignments. For interactive running the program requires 1 permanent and one scratch file for printed output. The test cases submitted were set up to use unit 11 as the permanent print file and unit 10 for the scratch. The scratch file unit 10 must be assigned for batch process operation.

Plot file requirements are unit 98 for the Cal-Comp output and a scratch unit 28 for interactive previewing of the Cal-Comp output. These four (4) unit assigments should be included in the basic JCL independent of the intended mode of operation. This setup will relieve the general user from the details of the load module.

Basic data setups have been provided for various rotorcraft. These data sets do not have the control card, in column 1, for exiting the data loading routine. These data sets were made up in this manner so that a basic load module can be added from the files. The user then need only to change any desired loader values, include the load exit card and execute the case. This type of set up minimizes the 'on-line' time for data run setups.

LIST OF ACRONYMS

A/C	Aircraft
CDP	Critical Decision Point
EMP	Engine Malfunction Point
HDP	Helicopter Dynamic Performance
LDP	Landing Decision Point
OEI	One Engine Inoperative
TEQ	Twin Engine Torque
TOSS	Take-Off Safety Speed
WAT	Weight-Altitude-Temperature

LIST OF SYMBOLS

H_C	Cyclic Flare Height - Ft
H_F	Collective Flare Height - Ft.
N_R	Rotor Speed in %
OW	Operating Weight
TPP	Tip Path Plane
V_H	Horizontal Speed - Kts
V_V	Vertical Speed - Ft./Min.
V	Velocity - Kts

4099-80